EURO 2019

UCD, DUBLIN, IRELAND

CONFERENCE ABSTRACT BOOK

Technical Program

Sunday, 17:30-19:00

■ SA-01

Sunday, 17:30-19:00 - O'Reilly Hall

Opening Session

Stream: Opening and Closing
Plenary session
Chair: *Seán McGarraghy*
Chair: *Luís Gouveia*

1 - **Opening Session**
Luís Gouveia, Seán McGarraghy

Opening session

Monday, 8:30-10:00

■ MA-01

Monday, 8:30-10:00 - O'Reilly Hall

Sally Brailsford

Stream: Tutorials
Tutorial session
Chair: *Inmaculada Rodríguez Martín*

1 - Introduction to hybrid simulation
Sally Brailsford

This tutorial provides a basic introduction to hybrid (or multi-paradigm) simulation, a modelling approach that combines two or more of the simulation methods discrete-event simulation, system dynamics, and agent-based simulation. Although simulation models containing both discrete and continuous variables have been developed since the 1960s, genuine hybrid simulation - as the term is understood today - only really came into existence in the 1990s. Initially it was mainly used within the disciplines of computer science and engineering, but in recent years there has been a rapid growth in interest among the operational research (OR) community. This is due in part to the wider availability and greater user-friendliness of commercial software for developing hybrid models, but the main reason for its increasing popularity among OR modellers is its ability to capture multiple aspects of complex real-world problems by exploiting the complementary strengths of the different methods. This talk provides a practical overview of the topic illustrated by some examples from the field of healthcare, presents some findings from a recent review of the literature from an OR perspective, and identifies promising areas for future research.

■ MA-02

Monday, 8:30-10:00 - Moore Auditorium

European Research Council

Stream: Special Session 1
Invited session
Chair: *Giovanni Felici*

1 - European Research Council: past results and future opportunities
Giovanni Felici

European Research Council (ERC) has confirmed its worldwide recognition as one of the most effective funding agencies for bottom-up, creative high-risk / hi-gain research in all fields of science. In this talk we will present the functioning of the different calls and the funding dynamics of ERC, followed by a closer look on the contributions that funded ERC projects are providing to our disciplines. Time will be devoted to discussion and to address questions from the audience.

■ MA-03

Monday, 8:30-10:00 - Q106

Speed networking and EURO working group on practice of OR

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Ruth Kaufman*

1 - Speed networking and EURO working group on practice of OR
Ruth Kaufman

One of the most important reasons for coming to a conference is to build your circle of professional acquaintance - with like-minded people who can encourage and inspire you, and with not-quite-so-likeminded people who can challenge and extend you, and with the many people who you can encourage, inspire, and challenge. However, it is not always easy to meet people when most of our time is spent sitting listening to presentations. The speed networking session is a supportive, managed way of meeting people you don't know: a series of short, quick-fire sharing of professional information with other participants, together with an exchange of contact details if you meet somebody you want to keep in touch with. Latecomers will be admitted but may have to wait for a few minutes before they can join in. The meeting will also include a short presentation about the EURO Working Group on Practice of OR, aimed at supporting a pan-European network of practitioners.

■ MA-05

Monday, 8:30-10:00 - A003

OR for Development and Developing Countries 1

Stream: OR for Development and Developing Countries
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Elise del Rosario*

1 - Public school location model for urban areas in developing countries
Jesica de Armas, Marta Reynal, Helena Ramalhinho Lourenco

Among the public services provided by any government, education is surely one of the most important. We put our attention on relatively poor areas with a sharp population increase tendency and where public schools are equally attractive, have the same quality, similar teaching, recreation spaces, tradition, and pupils from the same social stratum. In such areas, private schools are not common, walking is the most common means of traveling from home to school, and therefore the objective is equity oriented in terms of accessibility.

An example of this kind of areas is Ciudad Benito Juárez in Mexico. As this is currently under highly accelerated occupation, proactive measures to avoid the predicted collapse of the public education system are needed. New schools and modification of the current ones will be required, and this process should be developed using rational and broad supporting tools for decision makers, such as optimization models.

This work assesses the current primary school network in this city through a realistic and novel coverage location model. The current and future scenarios are compared to the optimal ones in terms of coverage at a certain walking distance, using an available budget to build and resize schools. The proposed model is quite flexible and easy to adapt to new considerations, allowing to apply it to regions in developing countries under similar conditions. Therefore, it can be provided as a general decision-making tool.

2 - A Multi-criteria Approach for Constructing a Reference-dependent Sustainable Human Development Index
Bijaya Krushna Mangaraj, Upali Aparajita, Shruti Surachita

The human development index (HDI) measures the human development performance of a country along three main socio-economic indicators: life expectancy at birth for a healthy life, adult literacy as an indicator of knowledge, and common logarithmic value of per-capita gross national income at purchasing power parity as an indicator of a standard of living. Countries compare themselves with respect to fixed target (FT), set by the UNDP, in order to improve their overall HDI values. This paper proposes a sustainable human development index (SHDI), by adding environmental dimension to the HDI that measures threats to human health and rises with economic growth and prosperity. As reference-dependent assessments are increasingly becoming popular in various evaluations, we suggest a multi-criteria methodology to determine a reference target (RT) for the countries under consideration based on peer comparisons. The model avoids the problem associated with the geometric mean, being used in the HDI, but retains the same theoretical intuitions of the post 2010 approach, i.e., the non-substitutability of the criteria. The RT attains the highest value in all four indicators, has the highest SHDI value and has the lowest shortfall from the FT. The countries are then ranked based on their relative closeness to the RT and are classified into four levels, so that they can prioritize their development strategies accordingly. We implement this model considering 180 countries for the SHDI ranking.

3 - Modeling pilgrim flows at the Kumbh mela
Ananth Iyer, Dalal Jyotirmoy

The Kumbh Mela is a bathing festival that attracts millions of pilgrims to specific locations where it is held, once every 12 years at each of 4 locations. We collected planning data regarding the Ujjain Kumbh Mela, created models to identify decision tradeoffs and thus generated strategic, tactical and operational models to manage people flows. Our models enable us to characterize the differences between the four Kumbh locations in Ujjain, Nasik, Allahabad and Haridwar, model the impact of resident vs visiting pilgrims preferences, model the impact of waiting time targets on resource requirements and model the benefit to flexible routing. A combination of planning reports and survey data is used to estimate the impact of choices on capacity required.

■ MA-06

Monday, 8:30-10:00 - A004

Energy Market Modelling Challenges

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: *Mel Devine*
Chair: *Valentin Bertsch*

1 - On limitations of optimization models for computing the equilibrium in competitive markets
Steffen Kaminski, Kris Poncelet, Erik Delarue

Before the liberalization of the energy markets a central planner (e.g. a government) faced the problem of determining a long-term investment plan, which minimized the total cost of the energy provision. As such, long-term planning models -formulated as optimization problems-were developed. Since the liberalization of energy markets, investments in generating capacity and operational decisions are made by private generation companies aiming to maximize their profits. Hence, there is no longer a central authority, instead market participants compete with each other forming a market.Both optimization and equilibrium modelling can be utilized to determine the market equilibrium. While the inherent assumption of perfectly competitive (e.g. price-taking) agents in optimization models is well known, there are other, less commonly known limitations, which restrict the use of optimization models for computing the market equilibrium. More specifically, certain market designs, policy interventions or behavioral assumptions of agents cannot be represented in optimization models. To the best of our knowledge, there is no general overview of these limitations and implications for simulating deregulated markets. To fill this gap, our contribution provides a descriptive analysis of the relation between optimization and equilibrium models, it highlights limitations of optimization models and eventually exemplifies the takeaways in an illustrative example of green certificate trading.

2 - Strategic operation of storage in energy markets: an EPEC approach
Mihály Dolányi, Kenneth Bruninx, Erik Delarue

In future energy systems with higher shares of renewable energy sources (RES), (distributed) energy storage systems (ESS) may play a crucial role in the generation mix. Energy storage systems add flexibility to the system and thus may compensate for the variability and imbalances caused by intermittent generation and demand. However, the distinct features of storage systems, e.g., their limited energy content, will affect the design and outcome of energy markets. To study the implications of a large scale introduction of distributed energy storage on energy markets, we employ a multi-period equilibrium model with equilibrium constraints. This approach enables us to model the strategic interactions of self-interested agents on a common market. In the model, we represent storage units, renewable sources and conventional generation as individual, profit-seeking agents through bi-level optimization problems. The market clearing is explicitly modeled and embedded in the lower level of each player's optimization problem. After merging the optimality conditions of the individual Mathematical Programs with Equilibrium Constraints (MPEC), we solve the resulting Equilibrium Problem with Equilibrium Constraints (EPEC) as a large-scale non-linear problem. In an illustrative case study, we demonstrate how the overall size of the storage owned by a single actor may lead to market power abuse by quantifying the changes in social welfare and the profitability of ESS.

3 - Pricing mechanisms and market designs in peer-to-peer electricity trading
Jens Weibezahn, Alexandra Lüth, Jan Zepter

The decline in the price of photovoltaic (PV) cells and battery storages in recent years has led to a broad implementation of small-scale PV installations in households - some including residential storage systems -, transforming customers into "prosumers" and increasing the rate of self-consumption in those households. This development also brought up the first pilot projects of local electricity markets in the form of so-called peer-to-peer trading platforms, in part based on the blockchain technology. Many pricing schemes lack however incentives to persuade households to invest e.g. in generation infrastructure.

We develop a model to assess pricing mechanisms and market designs in order to identify the main drivers in prices for a peer-to-peer market. Different scenarios for the situation of an alternative to the existing trans-regional electricity grid as well as for the construction of a local micro grid are being analyzed. The model is set up as an optimization model, resembling a local/regional market comprised of a number of model households representing heterogenous types of consumers and prosumers as well as battery storage owners/operators.

Preliminary results give an indication how local energy markets should be set up and operated with respect to remuneration schemes and pricing options in order to incentivize households to part-take and invest in the necessary infrastructure.

4 - Analysing long-term interactions between demand response and different electricity markets using a stochastic market equilibrium model
Valentin Bertsch, Mel Devine

Demand response (DR) as a source of flexibility is considered to become increasingly important in power systems based on renewable energy sources (RES), which are characterised by increasingly distributed, volatile and uncertain supply. We explore the impact of DR on generator investments and profits from different markets, on costs for different consumers from different markets, and on CO2 emissions under consideration of the uncertainties associated with the RES generation. We develop a novel stochastic mixed complementarity model in this paper that considers both operational and investment decisions, that considers interactions between an energy market, a capacity market and a feed-in premium and that takes into account the stochasticity of electricity generation by RES. We find that DR particularly increases renewable generator profits. While DR may reduce consumer costs from the energy market, these savings may be (over)compensated by increasing costs from the capacity market and the feed-in premium. This result highlights the importance of considering such interactions between different markets.

■ MA-07

Monday, 8:30-10:00 - A007

Stochastic Optimization

Stream: Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: Leif Meier

1 - Sustainable technologies for supplying packaging materials - a simulation based design
Thorben Rieck, Leif Meier, Frank Thomas

Due to increasing e-commerce volumes and therefore enormous increase in packaging materials, we investigate new technologies to reduce shipping bottlenecks and enable sustainable and environmental friendly packaging processes in a realistic case-study based on actual customer data. The simulation deals with the conception and analysis of the packaging supply of a fully automatic system by TUP.

Parameters investigated were order sequences, set-up time, distribution of packaging materials, processing time and order allocation to production lines and we proved reliable performance of designed system, stock optimization, dynamics depends on packaging set up and occupancy rate of each processing line.

Simulation results validates the design, allows to improve parameter settings and forecasts potential reductions of plastics usage in automated systems in reality.

2 - Applying evolutionary algorithms to the simulation-based optimization of the Viennese mass rapid transit network
David Schmaranzer, Roland Braune, Karl Doerner

We present a simulation-based headway optimization for urban mass rapid transit networks. Urban population growth, traffic congestion, efforts to reduce emissions as well as municipal ambitions to improve the quality of life for residents (e.g., by pedestrianization, reducing traffic, etc.) and tourism, make it necessary to continuously readjust urban mass rapid transit networks. The underlying discrete event simulation model contains several stochastic elements like time-dependent demand and turning maneuver times, direction-dependent vehicle travel and passenger transfer times. Passenger creation is a Poisson process which uses hourly origin-destination-matrices based on anonymous mobile phone and counting data. The number of passengers on platforms and within vehicles are subject to capacity restrictions. As a microscopic element, passenger distribution along platforms and within vehicles is considered. The bi-objective goals of cost reduction (measured in productive fleet mileage) and service level improvement (measured in mean waiting time per passenger) are transformed into a single-objective optimization problem by normalization and scalarization. Population-based evolutionary algorithms and different solution encoding variants are applied. Computational experience is gained from test instances based on real-world data. The covariance matrix adaption evolution strategy performed best in most cases. A newly developed encoding produced better short-term results.

3 - Black-box Combinatorial Optimization with Costly and Noisy Evaluations using Models with Integer-valued Minima
Laurens Bliek, Sicco Verwer, Mathijs de Weerdt

In many practical applications, an objective needs to be optimized for which no known mathematical formulation is known. If this objective can only be evaluated with costly and noisy measurements, most standard optimization algorithms are unsuited to find the optimal solution. Specialized algorithms to deal with exactly this situation make use of surrogate models. These models are usually continuous and smooth, which is beneficial for continuous optimization problems, but not necessarily for combinatorial problems. However, by choosing the basis functions of the surrogate model in a certain way, it can be guaranteed that the optimal solution of the surrogate model is integer. This approach is shown to outperform simulated annealing on a toy example, and outperforms both simulated annealing and Bayesian optimization on a noisy traveling salesman benchmark problem.

■ MA-08

Monday, 8:30-10:00 - A008

Statistical and Deep Learning Techniques for Energy Time Series

Stream: Modelling & Analytics for Energy Economics II
Invited session
Chair: Dogan Keles

1 - Can Time-Series Methods Improve the Accuracy of the Wind Energy Forecasts? Evidence from Ireland
Kevin Forbes, Ernest Zampelli

If the wind energy forecasts in Ireland are optimal, then the forecast errors will be purely random, i.e. "white noise." Based on Portmanteau (Q) tests for lags 1 through 100, the wind energy forecast errors in Ireland do not exhibit the white noise property. We also note that an OLS analysis reveals the errors in Ireland's wind energy forecasts have the undesirable property of being statistically related to forecasted weather conditions as well as the forecasted level of wind energy.

Based on the attributes of the forecast errors, an ARCH/ARMAX model is formulated. The structural regressors in our model include the level of forecasted wind energy, modeled meteorological conditions, a proxy for expected wind energy curtailments, and binary variables for the season and hour of the day. Our estimation approach is quite aggressive in its application of the ARCH/ARMA terms. Specifically, we estimate an ARMA(30, 48) model with a nonlinear ARCH(5) process.

The model is estimated using quarter-hour data over the period 1 January 2015 through 31 December 2016. The model has a R-squared of 0.997. The model is evaluated using out-of-sample data over the period 1 January 2017- 31 December 2017. The one-period-ahead forecasts have a weighted-mean-absolute-percentage-error (WMAPE) of about 4.2 percent. This is about one-third the WMAPE associated with the forecasts reported by Eirgrid over the same time period.

2 - Artificial Neural Networks in EPF: Are deep structures beneficial?
Grzegorz Marcjasz

Deep Neural Networks are currently gaining popularity, with many seeing them as the state-of-the-art modeling and forecasting technique.Their effectiveness in the context of the day-ahead electricity price forecasting was also shown by some researchers. Here, the overview of possible approaches and the use of forecast improvement frameworks, such as Variance Stabilizing Transformations, are presented along with potential issues and results of limited testing on diverse data sets originating from the United States and Europe.

3 - Stochastic simulation of spatial-temporal correlated renewable feed-in series
Benjamin Böcker

In future energy systems with a high share of renewable energy (RE), matching electricity demand and supply becomes increasingly challenging. The resulting need of flexibility strongly depends on the spatial and temporal coincidence of renewable infeed as well as on the existing grid. By utilizing spatial-temporal balancing effects of distributed renewable infeed, the flexibility needs can be reduced. The developed model combines different methods to meet with the challenges of RE infeed. Technical, regional, seasonal and time-of-day dependencies are key drivers of the actual infeed respectively the range of the expected infeed. The actual infeed is transformed into its quantile, which corresponds to the expected range by using quantile regression. For the modelling of photovoltaic infeed, this method allows to avoid the challenges in the morning and evening hours by shifting the perspective to cloud permeability. Multivariate Copulas are used to consider spatial as well as temporal correlations according to respective quantile within a stochastic process. The advantage of this model is shown in a selected application.

4 - Modeling of Control Reserve Prices using Econometric and Artificial Intelligence Approaches
Emil Kraft, Dogan Keles

In Germany, Transmission System Operators (TSOs) procure different reserve power products meeting different quality requirements through tenders. This leads to market segments for primary, secondary (automatic Frequency Restoration Reserve, aFRR) and tertiary control reserve power within the market for ancillary services. Besides reserve power markets, potential suppliers face several opportunities to market their flexible generation capacity. Therefore, forecasting of prices in several markets is crucial for market participants, for both taking the trading decision and placing optimal bids. This study focuses on the German aFRR market, which is the largest European one and consists of a two-part pay-as-bid auction for each 4-h-slice of the day. The modeling and forecasting of prices of ancillary services markets has been comparatively rare in the literature. We therefore explore methods to forecast aFRR prices and to identify different bidding strategies. Most of price forecasting models originate from either approaches based on time series analysis or from artificial intelligence or machine learning approaches. We apply SARIMA as well as regression models to aFRR price forecasting. The presence of intermittent spikes and nonlinearities makes the prediction very challenging. Therefore, we use also an artificial neural network (ANN) approach. We then compare the forecast quality of linear SARIMA and non-linear ANN models with and without additional external predictors.

■ MA-10

Monday, 8:30-10:00 - H0.12

Topics in Robust Optimization

Stream: Robust Optimization
Invited session
Chair: *Ihsan Yanikoglu*

1 - Robust parameter design and optimization for injection molding
Ihsan Yanikoglu

The aim of this study is to develop an optimization methodology to determine the values of the injection molding machine's key decision parameters for producing a specific product such that the desired quality level is attained in a shorter production cycle time. To demonstrate the idea, we focus on an injection molding product, a refrigerator door cap, made from a thermoplastic raw material and its key quality characteristic, warpage. The proposed robust parameter design and optimization approach uses the Taguchi methodology and robust optimization approach. After determining the optimal settings, they are implemented to the injection molding machine and parts are produced in compliance with the results reported in this paper. The numerical results show that the new designs significantly improve the warpage quality characteristic and the total production cycle time of the product compared with the current design of the manufacturing company.

2 - Robust Reformulations of Ambiguous Chance Constraints with Discrete Probability Distributions
Farzad Avishan

We propose robust reformulations of ambiguous chance constraints when the underlying family of distributions is discrete and supported in a so-called p-box or p-ellipsoidal uncertainty set. Using the robust optimization paradigm, the deterministic counterparts of the (ambiguous) chance constraints are reformulated as mixed-integer programming problems which can be tackled by commercial solvers for moderate sized instances. For larger sized instances, we propose a safe approximation algorithm that is computationally efficient and yields high quality solutions. The associated approach an the algorithm can be easily extended to joint chance constraints, nonlinear inequalities, and dependent data without introducing additional mathematical optimization complexity to that of the original robust reformulation. In numerical experiment, we first present our approach over a toy sized chance constraine knapsack problem. Then we compare optimality and computatonal performances of the safe approximation algorithm with those of the exact and the randomized approaches for larger sized instances via Monte Carlo simulation.

3 - Two-stage distributionally robust convex optimization with discrete uncertainty
Anirudh Subramanyam, Kibaek Kim

We study two-stage distributionally robust convex programs. By assuming only that a finite training dataset is available about the unknown parameters, we aim to determine a decision that performs best in view of the worst-case distribution among those that are contained within some chosen Wasserstein distance of the empirical distribution. Under this setting, recent works have studied single-stage convex programs as well as two-stage linear programs with continuous parameters supported on a polyhedron. In this work, we study two-stage convex conic programs with discrete-valued uncertain parameters. We extend recent results to show that this class of problems also admits an equivalent reformulation as a finite (single-stage) convex program. We also propose an exact algorithm for its solution, that is scalable with respect to the cardinality of the training dataset. We exemplify our results via several illustrative numerical examples. Our results directly extend to the classical robust optimization setting.

4 - The tight upper bound of sample variance over interval data: An easy NP-hard problem?
Ondřej Sokol, Miroslav Rada, Michal Cerny

Having interval-valued dataset, it is NP-hard to compute the tight upper bound of sample variance. However, polynomial-time algorithms were consctructed for various special cases. In our talk, we focus on the case where the number of intervals intersecting at any point is limited. Firstly, we propose an efficient implementation of the known algorithm and improve its asymptotic complexity. Secondly, we show that the special case covers surprisingly broad class of randomly generated datasets. Namely, we prove that if (i) the centers of the intervals in the dataset come from a continuous distribution with bounded density function and (ii) the radii of the intervals in the dataset are bounded from above, then the number of intervals intersecting in any point is limited in such a way that the algorithm works (on average) in asymptotically polynomial time in the number of obervations.

■ MA-11

Monday, 8:30-10:00 - H1.12

Vector and Set-Valued Optimization I

Stream: Vector and Set-Valued Optimization
Invited session
Chair: *Lidia Huerga*
Chair: *Vicente Novo*

1 - About a class of multicriteria microarray games and applications to medicine problems
Lucia Pusillo, Vito Fragnelli

In this paper, a class of multiobjective games with applications to a medicine setting is studied. We provide the notions of Shapley value and Banzhaf value for a multicriteria game and we apply them to a microarray game (introduced in Moretti et al. TOP, 2007; 15, 256-280). We give an axiomatic characterization too

2 - Recent developments of Ekeland's variational principle
Truong Q. Bao

This talk discusses recent developments of Ekeland's variational principle in quasi-metric spaces; i.e., a quasi-metric does not possess the symmetry axiom (in the case we allow the distance from one point to another point is not necessarily equal to the distance from the second point to the first point) and the coincidence axiom (in the case we allow the distance between two distinct points might be zero).

We propose a new unified way to establish versions of Ekeland's variational principle for vector-valued functions and set-valued maps. It combines Gerstewitz' nonlinear scalarization technique and variational tools. Doing this allows us to weaken assumptions on boundedness from below and lower semi-continuity. Examples are provided to illustrate improvements of the results.

3 - On unbounded convex vector optimization problems
Andrea Wagner, Firdevs Ulus, Birgit Rudloff

Benson's Algorithm is an approximation method for solving multi-objective optimization problems. It was further and further developed during the last years in order to make it applicable to a greater variety of programs. Amongst others, a variant for bounded convex vector optimization problems was introduced.

A necessary first step for solving convex vector optimization problems is to find an initial outer approximation. If the problem is unbounded, this is not always straight forward. While in case of vector linear programs this first step was done by solving a homogeneous linear program, the unbounded convex case was not treated yet. This study proposes a method that allows to find both an initial outer approximation and the set of minimal directions also for unbounded, convex problems, provided that the upper image is self-bounded.

4 - Characterization of approximate proper efficiency in vector optimization with difference of mappings
Lidia Huerga, César Gutiérrez, Bienvenido Jiménez, Vicente Novo

We introduce a notion of approximate proper efficiency in the sense of Henig for vector optimization problems and we study its main properties. Then, we focus on the particular case of a vector optimization problem whose objective mapping is given by a difference of two mappings, and we characterize its approximate proper solutions. For this purpose, a related epsilon-subdifferential for vector mappings is defined and its basic properties as well as a Moreau-Rockafellar calculus rule are derived.

■ MA-12

Monday, 8:30-10:00 - H1.51

Dynamic Flows and relevant application contexts

Stream: Combinatorial Optimization I
Invited session
Chair: *Maria Grazia Scutellà*
Chair: *Antonino Sgalambro*

1 - A Branch and Price Algorithm to solve the Quickest Multicommodity k-Splittable Flow Problem
Antonino Sgalambro, Anna Melchiori

In Network Optimization, k-splittable flows were introduced to enhance modeling accuracy in cases where an upper bound on the number of supporting paths for each commodity needs to be imposed, thus extending the suitability of network flow tools for an increased number of applications. Such modeling feature has recently been extended to dynamic flows with the introduction of the strongly NP-hard Quickest Multicommodity k-Splittable Flow Problem (QMCkSFP). The problem asks for routing and scheduling each commodity demand through at most k different paths in a capacitated dynamic network while minimizing the makespan of the process. We present the first exact algorithm for solving the QMCkSFP. The technique falls within the Branch and Price class and is based on original relaxation, pricing and branching procedures. Linearization and variable substitution are used to obtain the relaxation problem from the path-based formulation of the QMCkSFP. The pricing problem is modeled as a Shortest Path Problem with Forbidden Paths with additional node-set resources on a time expansion of the original digraph and is solved via a tailored dynamic programming algorithm. Two original branching rules are designed for restoring feasibility whenever k-splittable or binary variable domain constraints are violated. The results of an extensive batch of computational experiments conducted on small to medium-size instances are presented, showing a highly satisfactory performance of the algorithm.

2 - An inventory-routing problem for a large warehouse with a high degree of product rotation
Giacomo Lanza, Mauro Passacantando, Massimo Pappalardo, Maria Grazia Scutellà

We consider an inventory-routing problem critically impacting the performance of a large warehouse characterized by a high degree of product rotation. In a given time horizon, commodities are released from the production area and need to be stored in stocking areas, while commodities are requested to be picked from the stocking areas and delivered to a pre-loading area, from where they will be sent to final customers. Both stocking and picking have to follow peculiar management rules: storing should be performed in such a way that each commodity occupies contiguous areas, while picking should follow a first-in first-out criterion. Movements inside the warehouse are performed by two types of vehicles, whose routing is restricted to disjoint areas of the warehouse, and which may exchange commodities only at specific zones. The problem is formulated as a network optimization model on a time-space network, to represent the dynamics of the physical system over time. The objective is to minimize the cost of the operations by satisfying production and final customer requests, and by respecting the management stocking-picking rules and the capacity of both types of vehicles and of the different warehouse areas. Preliminary computational results based on real data are presented.

This work was supported by Region of Tuscany-Regional Government (POR FESR 2014-2020-Line 1-Research and Development Strategic Projects) through the Project IREAD4.0 under Grant CUP 7165.24052017.112000028

3 - Dynamic Flows under Travel Time Uncertainty
Arie Koster, Corinna Gottschalk, Frauke Liers, Britta Peis, Daniel Schmand, Andreas Wierz

We study dynamic network flows with uncertain input data under a robust optimization perspective. In the dynamic maximum flow problem, the goal is to maximize the flow reaching the sink within a given time horizon T , while flow requires a certain travel time to traverse an edge. In our setting, we account for uncertain travel times of flow. In this talk, we describe how the theory on dynamic flows can be extended to this case and focus on the computational complexity of the problem. We show that the dynamic robust maximum flow is considerably more complex than the already NP-hard static version. In particular, it is NP-hard to verify feasibility of a given candidate solution.

■ MA-13

Monday, 8:30-10:00 - H2.12

Discrete and Global Optimization I

Stream: Discrete and Global Optimization
Invited session
Chair: *Jan van Vuuren*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Peter Gritzmann*

1 - Extension of Dynamic Programming for Bi-criteria Combinatorial Optimization
Michal Mankowski, Mikhail Moshkov

The conventional dynamic programming algorithms for solving combinatorial optimization problems include a structure of subproblems of the initial problem. Such algorithms return only one solution. We designed an extension of the dynamic programming approach that allows us to construct the set of Pareto optimal points for a bi-criteria optimization problem. We propose a fairly universal framework to work with combinatorial optimization problems which is based on the use of so-called circuits without repetitions. Such circuits represent the sets of elements under consideration and are used by bi-criteria optimization algorithms. To evaluate our framework, we constructed circuits without repetitions for multiple combinatorial optimization problems such as convex polygon triangulation, optimal binary search tree, one-dimensional clustering, line breaking, or sequence alignment. We evaluated the number of operations required by the optimization algorithm and considered the results of the experiments. We recognized an element that is optimal relative to two cost functions at the same time. We evaluated the existence of such elements and constructed Pareto fronts for considered problems.

2 - On grain map reconstruction
Peter Gritzmann

The problem of understanding the granular structures of polycrystals is of basic interest in material sciences. Here we focus on the discrete inverse problem of reconstructing grain maps from only few measured parameters (volume, center and, possibly, moments) for each grain. We develop an optimization model for balanced clusterings which leads to an efficient algorithm for computing appropriate anisotropic diagrams.We demonstrate its favorable behavior both theoretically and for real-world data.

(Joined work with A. Alpers, A. Brieden, A. Lyckegaard and H. Poulsen)

3 - Theoretical Results for the Multiple Traveling Salesperson Problem on Regular Grids
Anna Jellen, Philipp Hungerländer, Stefan Jessenitschnig, Lisa Knoblinger, Manuel Lackenbucher, Kerstin Maier

In this work we analyze the multiple Traveling Salesperson Problem (mTSP) on regular grids. While the general mTSP is known to be NP-hard, the special structure of grids can be exploited to explicitly determine optimal solutions, i.e., the problem can be solved in linear time.

Our research is motivated by several real-world applications, like search and rescue operations or delivering goods with swarms of unmanned aerial vehicles (UAV). Regular grid structures can be used to divide large search areas in several equal-sized squares. The size of a square is chosen as large as the sensor or camera range of a UAV.

First, we suggest a Mixed Integer Linear Program (MILP) for the mTSP on regular grids where we distinguish between two objective functions. The first one aims to minimize the total tour length of all salespersons, which is motivated by minimizing the average search time for a missing person. The second objective function minimizes the maximal tour length of a single salesperson, which is motivated by minimizing the maximal search time for a missing person.

With the help of these MILPs and combinatorial counting arguments, we establish lower bounds, explicit construction schemes and hence optimal mTSP solutions for specific grid sizes, depot positions and number of salespersons.

■ MA-15

Monday, 8:30-10:00 - H2.32

Optimization and Equilibrium Problems on Riemannian Manifolds

Stream: Mathematical Programming
Invited session
Chair: *Sándor Zoltán Németh*

1 - A Variational Model for Data Fitting on Manifolds by Minimizing the Acceleration of a Bézier Curve
Ronny Bergmann, Pierre-Yves Gousenbourger

Fitting a smooth curve to a set of n data points lying on a Riemannian manifold and associated with real-valued time points is a common problem in applications like wind field approximation, rigid body motion interpolation, or sphere-valued data analysis. The resulting curve should strike a balance between data proximity and a smoothing regularization constraint.

In this talk we present a variational model to fit a composite Bézier curve to the set of data points on a Riemannian manifold. The resulting curve is obtained in such a way that its mean squared acceleration is minimal in addition to remaining close the data points. We approximate the acceleration by discretizing the squared second order derivative along the curve. We derive a closed-form, numerically stable and efficient algorithm to compute the gradient of a Bézier curve on manifolds with respect to its control points. This gradient can be expressed as a concatenation of so called adjoint Jacobi fields. Several examples illustrate the capabilities of this approach both for interpolation and approximation.

2 - Iteration-complexity of steepest descent method for multiobjective optimization on Riemannian manifolds
Orizon P Ferreira, Mauricio Louzeiro, Leandro Prudente

The steepest descent method for multiobjective optimization on Riemannian manifolds with lower bounded sectional curvature is analyzed in this paper. The aim of the paper is to present iteration-complexity bounds for this method. In addition, some examples are presented to emphasize the importance of working in Riemannian setting.

3 - Optimality conditions for non-differentiable multiobjective program on Riemannian manifolds
Glaydston Bento

It is known that optimality criteria form the foundations of mathematical programming both theoretically and computationally. In this talk optimality conditions for multiobjective optimization problems will be approached which allowed to consider the proximal point method without any assumption of convexity over the constraint sets that determine the vectorial improvement steps throughout the iterative process.

4 - On the spherical quasi-convexity of quadratic functions on spherical self-dual convex sets
Sándor Zoltán Németh, Orizon P Ferreira, Lianghai Xiao

This talk is about spherical quasi-convexity of quadratic functions on spherically self-dual sets. Sufficient conditions for spherical quasi-convexity on self-dual sets are presented. A partial characterization of spherical quasi-convexity on spherical Lorentz sets is given and some examples are provided.

■ MA-16

Monday, 8:30-10:00 - Theatre A

Supply Chain Scheduling and Logistics

Stream: Combinatorial Optimization II
Invited session
Chair: *Alena Otto*
Chair: *Dominik Kress*
Chair: *Erwin Pesch*

1 - Locating Platforms and Scheduling a Fleet of Drones for Emergency Delivery of Perishable Items
Alessandro Agnetis, Monica Gentili, Pitu Mirchandani

We consider an integrated location-scheduling problem concerning the use of unmanned aerial vehicles (drones) for sending perishable supplies to demand points that are not easily reachable otherwise, as it occurs when essential medical supplies must be shipped to communities in rural or underdeveloped regions. In our scenario there is a set of n demand points. Each demand point must receive a package, and depending on the package delivery time, the demand point incurs a certain disutility (cost), typically nondecreasing with the delivery time. There is a set of potential locations for drone platforms. The problem is to jointly locate drone platforms, assign a set of demand points to each drone (within the drone platform range) and schedule the drones' tasks so that total disutility is minimized. We consider two problems: (i) a single-period problem (e.g. one day), in which all deliveries have to be completed within the period, and (ii) a two-period problem, in which deliveries can be carried out across the two periods, and a limited number of drone platforms can be relocated between the two periods (e.g. overnight). We propose time-indexed formulations for both problems and present computational results, addressing managerial issues such as: the impact of the number of drones and their radius on the quality of service, as well as the benefits of relocating drones vs. increasing their number.

2 - Optimally scheduling a single crane in an automated storage and retrieval system
Simon Emde, Lukas Polten, Michel Gendreau

This paper investigates the problem of scheduling a set of jobs on a single batching machine to minimize the maximum lateness, where jobs may be subject to precedence constraints and incompatibilities. Single batching machine scheduling has many applications, but this study is particularly motivated by single crane scheduling in an automated storage and retrieval system (AS/RS): given a set of transport requests, which requests should be processed together in the same dual command cycle, and in what order should the cycles be processed? Since storage and retrieval requests may refer to the same physical item, precedence constraints must be observed. Moreover, the crane may not be capable of handling multiple storage or retrieval requests in the same cycle, hence the need to account for incompatibilities. We present a novel exact algorithm based on branch & Benders cut, which is shown to solve even large instances with more than 100 jobs to optimality in many cases. For the special case without precedence constraints and incompatibilities, it improves on several best-known upper bounds from the literature.

3 - Who should collect? Collection cost and reverse channel configuration
Nora Dörmann, Jochen Gönsch

Choosing the optimal reverse channel configuration requires analysis of the underlying collection cost structure and its impact. A manufacturer who remanufactures his own products can choose between managing collection of used products himself, let the retailer manage collection or involve a third party company to manage collection. In particular, we consider a convex collection cost function that depends on the collection rate. Contrary to previous literature, we discuss that the manufacturer always prefers retailer-managed collection, independent of collection cost. The retailer will always choose a positive collection rate. If collection cost is above a certain threshold, not all used products will be collected and the manufacturer (almost) collects all channel profits. Third party-managed collection is always dominated.

4 - Optics and optimization
Eitan Bachmat

We will explain a simple basic relation between certain resource allocation problems and optics. We will then show more specifically how we can construct certain optimal airplane boarding strategies by constructing thin focal lenses for electrons in the setting of space-time (relativistic) geometry.

■ MA-18

Monday, 8:30-10:00 - C112

Ensemble Learning Applications for Business Analytics

Stream: Multiple Classifier Systems and Their Applications
Invited session
Chair: *Koen W. De Bock*
Chair: *Sureyya Ozogur-Akyuz*

1 - Ensemble Methods in Dynamic Pricing
Dirk Sierag

In this case study a scalable dynamic pricing method is applied to several datasets. The goal is two-fold: (1) improve forecast accuracy, and (2) optimize prices. The method exploits ensemble techniques to estimate parameters and price-sensitivity functions, which are subsequently used to optimize prices. Along with performance results of our method, we will discuss the impact of feature selection/engineering on these datasets and the relationship between forecasting accuracy and price optimization.

2 - Interpreting the Corporate Bankruptcy Forecasts: A Hybrid Bayesian Network Model
Yi Cao, Xiaoquan Liu, Jia Zhai, Shan Hua

Despite their empirical success and popularity in the area of healthcare diagnosis, Bayesian network models are rarely considered in bankruptcy prediction although the two areas address research questions of a similar nature. In this study, we develop an interpretable hybrid Bayesian network model for predicting firm bankruptcy probability. To construct the model, we select relevant accounting and financial ratios by the least absolute shrinkage (LASSO) logistic regression model, establish the topology of a Bayesian network with selected variables, and obtain parameter estimates for conditional probabilities by the expectation-maximization algorithm. Our empirical results, based on a comprehensive dataset of 32,344 US firms between 1961-2018, show that our Bayesian network model outperforms five popular alternative models and is outperformed only by the deep neural network model in terms of prediction precision. Crucially, our hybrid Bayesian network provides a clear interpretation of model internal functionality by offering the logic reasoning process of how the final conditional default probability is achieved and the sensitivity of the conditional probability with respect to changes in input variables. Our model represents the first step towards interpretable machine learning methods for obtaining bankruptcy probability prediction with great accuracy.

3 - Use of Social Media Big Data for Predicting the Credit Ratings of Companies
Leonie Tabea Goldmann, Jonathan Crook, Raffaella Calabrese

Predicting the financial performance of companies using various data sources has been the focus of a large number of studies. However, current models can still be improved to achieve even better predictions. This research makes three contributions to knowledge. First, this research introduces a new method to more accurately predict the probability that a company's credit rating stays the same or will change.

More specifically, this research exploits the vast increase in social media data put out by companies, that enables one to develop more predictive models than those developed in the past. By analysing the tweets put out by different companies, we show that there is a correlation between specific words in the tweets and the credit rating. Furthermore, we will show that using these words in a predictive model leads to an increase in predictive power when comparing with a model not containing these words as predictors. Second, we are using differential language analysis for identifying linguistic features in tweets that are most predictive of a change in credit ratings, a method which is usually used in psychology and health and has not been used in a financial context before. Third, we use a very large and unique dataset of variables from different frequencies for the analysis. For instance, tweets from 2016 to April 2018 are considered as well as data on the companies, such as their size or their sector of a large sample of NYSE listed companies.

4 - Enhancing Material Profiling in Automotive Supply Chains via Principal Component Analysis and K-means Clustering

João Gonçalves, Paulo Cortez, Sameiro Carvalho

Complex Supply Chain (SC) networks encompass erratic behaviors that pose challenges in the field of supply chain management. This occurs at a time where available data is rapidly increasing in both volume and variety. By using real-world data from a major automotive electronics SC, this paper takes advantage of unsupervised learning approaches to detect and grasp important patterns among several logistic features that coexist in this context. Concretely, Principal Component Analysis (PCA) is first employed to analyze and understand the interrelations between ten quantitative and dependent variables associated with different types of raw material and suppliers. Afterwards, the Principal Component (PC) scores are characterized via a K-means clustering. As a result, K-means based on the PC scores enabled us to classify the samples into four clusters and to derive different profiles for multiple raw material parts. Overall, the combination between K-means and PCA enabled the finding of interesting logistic feature-patterns, showing its relevance in improving raw material inventory management in dynamic supply chains.

■ MA-19

Monday, 8:30-10:00 - C115

Knowledge Management Analytics

Stream: Knowledge and Knowledge Analytics

Invited session

Chair: *A. D. Amar*

Chair: *Uttarayan Bagchi*

1 - Hierarchical Document Classification using Overlapped Features

Daiki Min, Jeen-Young Kim

The rapid growth of digital documents has recently motivated the research on classifying documents to efficiently exploit information contained in the documents. However, there are several obstacles degrading classification performance. These include hundreds of multinomial classifiers, high levels of similarity between classes, class size imbalance, high dimensional representation space, and a low frequency of discriminative features. This paper proposes a feature selection methodology to classify documents sequentially by generating binary tree hierarchies. In document classification problems, low inter-class similarity is generally preferred for improving classification performance. Unlike the conventional methods, we mainly focus on the use of features that have high inter-class similarity for classifying non-structured documents. Numerical examples on scientific papers about rainwater harvesting, which is a technology designed to cope with climate change, are given to show the effectiveness of the proposed hierarchical feature selection scheme.

2 - Category Portfolio and Shelf Positioning Optimization in Multi-Brand Retail Outlets: A Case Study in the UAE

Santanu Roy, Krishnapriya Sudheesh

The subject of retail productivity has assumed a critical dimension in the recent past. The work reported here was carried out within the context of a multi-brand retail chain conglomerate, headquartered in one of the large Emirates in the UAE. Specifically, the Food and Home supermarkets run by this chain formed the context of the study. Five retail outlets were selected keeping in view the similarities in customer demography (nationalities/food habits) and economic background. For carrying out category portfolio optimization, data of the entire stock keeping units (SKU) inventoried across these five outlets of the retail chain, belonging to eight master categories, were considered. Dead/slow moving SKUs were identified and then eliminated from further consideration. Next, space productivity indices and gross profit margins of 13 master categories were evaluated, again at an aggregate level, leading to the selection of five top-selling master categories. As a part of the category-shelf location optimization process, the exact zone locations of the selected five master category-shelves within each of the five stores were mapped out. The space productivity indices of category-shelf/zone combination in each of the retail outlets were used in the form of an input matrix to an assignment model, solved through HungarianAlgorithm.com software. The optimized category-shelf/zone combination showed an increase in store profits compared to the current profits, validating our model.

3 - Knowledge Management's Key Challenge: How Do We Accelerate Learning?

Uttarayan Bagchi, Amitava Dutta

Different organizations learn at different rates. If, as has been argued, the only sustainable advantage you as an organization may have is your ability to learn faster than your competitors, the key challenge organizations in the knowledge economy face is how to accelerate learning. We explore both what speeds up learning and what slows down learning. We consider the relative importance of managing existing knowledge and creating new knowledge. We also articulate specific steps for individuals and organizations striving to learn faster.

4 - Data-Driven Evidential Reasoning Approach for Automobile Insurance Fraud Detection

Xi Liu

Machine learning models have gained an increasing amount of attention in learning complex patterns; however, the added complexity has come at the cost of model interpretability. This paper aims to develop a transparent intelligent automation system which can provide a decision by acquiring evidence and evaluating the reliability of evidence from the training data. We establish a unique Evidential Reasoning (ER) rule to combine multiple independent pieces of evidence. Each piece of evidence is weighted and then combined conjunctively with the weights optimised by using a maximum likelihood evidential reasoning (MAKER) framework for data-driven inferential modelling. Based on the a real-world insurance claim fraud dataset, our experimental results reveal that the proposed approach preserves the interpretability and usability of expert detection system, and anticipates the changes in fraud practices by tracking the trend of the weights of experience-based indicators. Furthermore, the experimental results show that the proposed approach outperforms a number of widely used machine learning models, such as random forests and support vector machine.

■ MA-22

Monday, 8:30-10:00 - F102

Production Planning and Control for Semiconductor Manufacturing I

Stream: Production Planning and Control for Complex Manufacturing Systems

Invited session

Chair: *Lars Moench*

Chair: *Thomas Ponsignon*

1 - Characterizing Customer Ordering Behaviours in Semiconductor Supply Chains with Machine Learning Approaches
Thomas Ponsignon

Advancements in semiconductor industry have resulted in the need for extracting vital information from vast amount of data. In the operational processes of demand planning and order management, understanding customer demand data provides important insights for managing supply chains. Machine learning approaches offer potential to identify latent information from multitudinous customer demand data and support enhanced decision-making. In this paper, we propose a method to visualize customer ordering behaviour in the form of heatmaps. Then, the application of these heatmaps is illustrated with different scenarios inspired from situations encountered by a semiconductor manufacturer. We discuss the usage of machine learning approaches for the automated identification of ordering patterns in the heatmaps. Finally, some directions for further research are outlined.

2 - Modeling an Ontology for Planning and Control Tasks in Semiconductor Value Chains
Sebastian Arens, Lars Moench

In this talk, we discuss how we can ensure interoperability of different planning components, for instance software agents, in semiconductor value chains by means of a domain- and task-specific ontology. The sheer size of the facilities and the supply chains in the semiconductor domain, the permanent appearance of uncertainty, and the rapid technological changes lead to an industrial environment that gives rise to applying software agents for next-generation enterprise information systems. Our ontology is designed based on a domain analysis. It considers especially demand fulfillment and engineering activities. The usage of the proposed ontology is illustrated by examples.

3 - Scheduling Jobs with Uncertain Ready Times on Batch Processing Machines
Lars Moench

In this talk, we consider a scheduling problem for batch machines. A batch is a group of jobs that are processed at the same time on a single machine. The jobs belong to incompatible families. Only jobs of the same family can be batched together. Each job has a weight, a due date, and a release date. The performance measure of interest is the total weighted tardiness. The ready times are calculated based on the information related to upstream machines that is stored in a Manufacturing Execution System (MES). Therefore, they are often uncertain. We propose a metaheuristic approach. Sampling is used to take into account the uncertainty of the ready times. Results of computational experiments are reported that show that this approach performs well with respect to computing time and solution quality.

■ MA-23

Monday, 8:30-10:00 - F103

Brick-and-Mortar Store Management and In-Store Logistics

Stream: Demand and Supply Management in Retail and Consumer Goods
Invited session
Chair: *Maria Antónia Carravilla*

1 - Stores closures generate a ripple effect - An investigation of exit dynamics in the retailing market
Roberta Taramino, Luigi Buzzacchi, Alberto De Marco, Giulio Zotteri

More than ever before, traditional urban retail systems are endangered. On-line shopping, upsurges in competition, recession and market saturation are, among the causes of a slow but steady transformative process, leading to the closure of physical stores throughout the city. If the presence of empty spaces within the urban tissue is an issue by itself, the closure of retailers is even worse. Indeed, they play a vital role on the liveability of a city by contributing to the vitality and the attractiveness of the neighbourhood. As an even bigger problem, ripple effects might emerge as a consequence. Indeed, the agglomeration of empty spaces in a suburb tend to move consumers, who are more likely to purchase in attractive places, elsewhere. This consumers' reaction might speed up the closure of retailers that are still active in that neighbourhood which has become more and more unpleasant. The paper investigates the exit dynamics of retailers in the context of urban systems with a specific focus on spatially clustered negative feedback mechanisms that are triggered by such emptying process of commercial space. Empirical tests have been developed around a wide dynamic dataset of commercial licenses in the second largest city in the North of Italy. Distance Based Measures are applied to empty spaces in order to assess the intensity of the negative spillover that closing a store generates on nearby retailers.

2 - Distribution Network Design with Product Allocation to Different Types of Distribution Center
Tobias Potoczki, Heinrich Kuhn, Andreas Holzapfel

We examine a distribution network design problem that integrates both the strategic decision of determining the number of distribution centers (DC), their location and store assignments, as well as the decision of allocating products to different types of DCs. The underlying distribution network structure is that of grocery retailers who choose to operate several types of warehouses which store a distinct set of products each. We propose an MIP solution approach considering costs which result from operating the warehouses, inbound transportation, inventory holding at the DCs, outbound transportation and instore logistics.

3 - Dynamic Labour Allocation in Retail Stores: Mathematical models and Performance Evaluation
Shandong Mou, David Robb

Aligning staff with changing customer and store needs is of great importance in retail store operations management. Mismatches between customer demand and service supply will reduce store profitability. There is considerable research on personnel scheduling, but little on the common phenomenon of Real-Time Labour Allocation (RTLA), where mismatches between workforce supply and demand are addressed by allocating cross-trained employees among store areas (or departments) in real time. Our interviews with retail practitioners confirm that RTLA decisions lack analytical justification. We model RTLA decisions using a finite horizon discrete-time stochastic dynamic programming framework, considering both operational and human resource-oriented objectives. To deal with the high-dimensional state space, we adopt an Approximate Dynamic Programming (ADP) framework. We extend a testbed that is previously published for one-off workforce allocation among departments at the beginning of a shift. We compare the performance of ADP-based solutions with static (complying with the initial schedules), greedy, and myopic policies, under various demand scenarios and cross-training configurations. Computational results show ADP-based solutions outperform other policies.

■ MA-24

Monday, 8:30-10:00 - F103A

Supply Chain Management: inventory control

Stream: Supply Chain Management
Invited session
Chair: *Stelios Koukoumialos*

1 - Managing Inventory in the Presence of Lead Time and Demand Correlation
Fouad Mirzaei, S. Yasaman Amirkiaee, Shailesh Kulkarni, Andy Tsay

Many studies assume lead time and daily demand are independent. In this study, we relax this assumption for a continuous review inventory system and analyze the characteristics of the optimal ordering policy. We investigate how firms should react to the presence of demand-lead time correlation to gain higher profits. When demand and lead time are independent, a lower demand or lead time uncertainty always cause a lower total cost. For they are correlated, we show that a lower demand or lead time uncertainty generate a higher cost in some circumstances. Moreover, there exists at least one correlation coefficient for which the total inventory cost is a convex function of uncertainties. Next, we study the situation when the demand and lead time distributions are unknown. Considering the demand and lead time dependency complicates matters, yet it leads to more generalized and robust recommendations.

2 - Planning capacity and safety stocks in a production-distribution system with multiple products
Foad Ghadimi, Tarik Aouam

This work jointly optimizes capacity planning and safety stock placement in a production-distribution system under the guaranteed service approach. The network under consideration consists of a manufacturer, a warehouse and a retailer in tandem. The integrated problem sets the capacity of workcenters at the manufacturer and safety stocks at the warehouse and retailer, while taking into account the link between capacity, production cycle times and safety stocks. The relationship between lead times and optimal safety stock placement is characterized in a single workcenter, and efficient solution procedures are developed. These procedures are used in a Lagrangian relaxation algorithm to solve the integrated problem when the manufacturer has multiple workcenters. A simulation framework is presented for setting capacity and safety stocks in the production-distribution system. This framework is used to evaluate the quality of the solutions and the accuracy of the model. A simulation study is conducted to compare the solutions of the proposed integrated approach with two existing approaches for determining capacity and service times and to illustrate the effect of various parameters on the solutions and performance measures of the integrated approach. Computational experiments show that the Lagrangian relaxation algorithm is able to find optimal or near-optimal solutions in reasonable CPU times and outperforms a commercial solver in terms of average optimality gap and run time.

3 - The Optimal Spares Allocation in a Two Echelon Multiple Location Facility with Periodic Review and Customer Patience
Yahel Giat, Michael Dreyfuss

We study a two-echelon inventory system with Poisson arrivals and stochastic order lead times under a periodic review policy. The inventory system comprises multiple locations in the lower echelon and a depot in the top echelon. The system's performance measure is the window fill rate, which is defined as the probability that a random customer is served within a given time window. The appeal of the window fill rate is that it incorporates the fact that customers usually tolerate a certain wait either due to patience or as a result of contractual agreement. We develop approximating formulae for the window fill rate and consider the spares allocation problem which is finding the spares allocation that maximizes the window fill rate subject to a given budget of spares. We develop an algorithm in which we allocate different levels of spares to the depot and solve the optimal lower echelon allocation for the remaining budget. The algorithm's output is the optimal number of spares in the depot and the corresponding lower-echelon allocation. We show how this algorithm's accuracy can be improved by integrating simulation into one of its steps, with a nonrestrictive loss to running time. Additionally, we show how our algorithms may be used to solve the continuous review setting efficiently.

4 - Optimal inventory replenishment policies in continuous review multistage supply chains with lost demand and exponential lead times
Stelios Koukoumialos, Michael Geranios, Michael Vidalis, Alexandros Diamantidis

Inventory control is a crucial factor for the supply chain survival, especially when excess demand is lost. Relevant literature presents very little on the subject of optimal replenishment policy in lost-sales inventory systems. The supply chain under consideration consists of an arbitrary number of stages serially connected. External demand and lead times of every stage to its immediate downstream stage are stochastic. All stages follow continuous review (s, Q) inventory control policies. If node's stock is insufficient, then the downstream order is partially satisfied with the rest being lost. The system is modeled as a continuous time - discreet space Markov process. We explore the transition matrix for different values of (s, Q) for any number of stages and we develop a computational algorithm to provide various performance measures. The proposed algorithm determines the optimal inventory policies for every stage, given constraints on the minimum fill rate or maximum WIP of the examined supply chain. We obtain the optimal replenishment policy given a total available inventory capacity for all stages, via enumeration for short systems or by Hooke-Jeeves search method for longer chains. Additionally, the best configuration of the system parameters to minimize a total cost function is also explored.

■ MA-25
Monday, 8:30-10:00 - F104

Cutting and Packing 1

Stream: Cutting and Packing
Invited session
Chair: Julia Bennell

1 - The expanding space method in sphere- and circle packing problems
Sergiy Yakovlev, Iryna Yakovleva

A problem of packing unequal spheres and circles, which radii are known, into containers of various shape are considered. An equivalent mathematical model to a standard sphere- and circle packing model is formed based on the assumption that the radii may be variable. In the new model formulated in a higher dimension space, a combinatorial structure is derived, and additional constraints are formed involving variable radii and providing its equivalence to the original packing problem. This approach of treating radii as variables allows improving local solutions of the original problem. Based on different rules for choosing the radii, specifics of applying optimization techniques for obtaining global solutions is studied. Numerical results of solving test problems of packing unequal spheres and circles are given.

2 - Two-dimensional cutting and packing problems - A Review
Gerhard Wäscher, Yiping Lu

In this paper, a review of two-dimensional cutting and packing problems dealt with in the literature during the decade from 2008 to 2017 will be given. We will propose factors which can be used for defining more homogeneous problem categories and identify areas research has focused on. Also promising areas of future research will be pointed out. The paper extends the typology of Wäscher et al. (2008) and complements the review of Bortfeldt and Wäscher (2013) on three-dimensional problems.

3 - Integrating nesting and cutting path determination problems
Franklina Toledo, Larissa Oliveira, José Fernando Oliveira

The irregular strip packing problem, also known as nesting problem, consists of finding a layout for small pieces that must be cut from a larger object with fixed height and infinite length. The goal is to minimize the length required to cut all the pieces ensuring that they do not overlap each other and that all of them are completely inside the object. The main characteristic, and at the same time the main difficulty, of this problem is the irregular shape of the pieces. In some industries, after a layout (the solution of the nesting problem) has been defined, a second problem arises: the determination of the cutting path. The cutting path determination problem aims to determine the shortest path length required to cut all the pieces. The solution of the first problem strongly influences the resolution of the second. To tackle this problem, we propose an integrated approach to solve the irregular strip packing and the cutting path determination problem.

4 - A solution approach for the two-dimensional cutting stock problem with usable leftovers and uncertainty in demand
Douglas Nogueira do Nascimento, Adriana Cherri, José Fernando Oliveira, Beatriz Brito Oliveira

In this work, we deal with the two-dimensional cutting stock problem with usable leftovers (2DCSPUL) and demand uncertainty. As all cutting and packing problems, the 2DCSPUL has great practical importance for many companies, with a substantial economic and environmental impact, due to the reduction in the waste of raw materials. However, in the 2DCSPUL this waste reduction is leveraged by using adequate leftovers of previous cutting processes. Therefore, the main difficulty of this problem is planning the production of both demanded items and leftovers in a multiperiod perspective without knowing the future demand. We propose a mathematical model to represent the 2DCSPUL with demand uncertainty, which considers that the object to be cut is divided into strips, whose heights are determined by the largest item in that strip. Also, different items can be combined into a single macro-item, while leftovers have given sizes and can be generated within a limited amount. Regarding solution methodology, the solution of the model with a commercial solver is hybridised with a genetic algorithm that simultaneously develops solutions and scenarios that adequately represent uncertainty in demand. Computational experiments were performed with instances generated with a problem generator. The obtained results were very satisfactory. This research has been supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP [2018/16600-0], [2018/07240-0] and [2016/01860-1].

■ MA-26
Monday, 8:30-10:00 - F106

Scheduling and staffing in large service systems

Stream: Service Operations Management
Invited session
Chair: Marko Boon
Chair: *Stella Kapodistria*

1 - Many-server scaling of the N-system under FCFS-ALIS
Dongyuan Zhan, Gideon Weiss

The N-system with independent Poisson arrivals and exponential server-dependent service times under the first come first served and assign to the longest idle server policy has an explicit steady-state distribution. We scale the arrival rate and the number of servers simultaneously, and obtain the fluid and central limit approximation for the steady state. This is the first step toward exploring the many-server scaling limit behavior of general parallel service systems.

2 - Design heuristic for parallel many server systems
Marko Boon, Ivo Adan, Gideon Weiss

We study a parallel queueing system with multiple types of servers and customers. A bipartite graph describes which pairs of customer-server types are compatible. We consider the service policy that always assigns servers to the first, longest waiting compatible customer, and that always assigns customers to the longest idle compatible server if on arrival multiple compatible servers are available. For a general renewal stream of arriving customers, general service time distributions that depend both on customer and on server types, and general customer patience distributions, the behavior of such systems is very complicated. Key quantities for their performance are the matching rates, the fraction of services for each pair of compatible customer-server. Calculation of these matching rates in general is intractable, it depends on the entire shape of service time distributions. We suggest through a heuristic argument that if the number of servers becomes large, the matching rates are well approximated by matching rates calculated from the tractable bipartite infinite matching model. We present simulation evidence to support this heuristic argument, and show how this can be used to design systems with desired performance requirements.

3 - Overflow in Service Systems
Jingui Xie

In the healthcare service, a healthcare provider usually has a dedicated population of patients. To improve system operational performance, some systems adopt process flexibility and allow patients to overflow from the primary provider to a secondary provider. This performance improvement is at a cost of wrong assignment and malposition. In this paper, we aim to analyze a service system with overflow and characterize the conditions under which allowing patients to overflow is preferred.

■ MA-27
Monday, 8:30-10:00 - F107

Network Optimization in Telecommunications I

Stream: Telecommunications and Network Optimization
Invited session
Chair: Charl Ras

1 - Reconfiguration of Service Function Chains: Trade-off between Optimality and Effort
Kyoomars Alizadeh Noghani, Andreas Kassler

Optimal placement of Virtual Network Functions (VNFs) in the network enhances the overall performance and decreases the operational costs for mobile network operators. However, a VNF placement that was optimal at a time may become suboptimal when resource demands, objectives, and parameters in the network change. This requires to reconfigure the network and service chains to cope with new requirements. Network reconfigurations can be very challenging and distressing for network providers as they may lead to significant service disruptions, performance degradation, and revenue loss. On the other hand, not changing the existing placement may lead to a sub-optimal operation, servers and links may become congested or underutilized, leading to high operational costs. As a result, it is crucial to investigate the tradeoff between reconfiguration of VNFs and the optimality of the resulting placement and service flow routing. We formulate a joint optimization problem which aims to minimize both the total cost of the VNF placement and the reconfiguration cost to repair a sub-optimal placement. The numerical evaluation shows that with a small number of reconfiguration steps, an infeasible or sub-optimal placement can be repaired leading to a significant cost reduction for the energy to run the NFV infrastructure. On the contrast, making a sub-optimal placement optimal may entail a large number of reconfigurations, which may not pay off at the end.

2 - New scenarios for resource slicing and sharing in beyond 5G networks
Antonio Capone
The introduction of 5G is radically changing the mobile network architecture with new instruments for virtualizing most of the basic network functions, facilitating the programmability of application specific functions both at network core and edge, and partitioning the radio access and transport resources so as to optimize the support of a large set of vertical application scenarios. This evolution has required a big research effort to tackle non-trivial technological problems. However, the new scenario is stimulating quite big changes in the economic relations and in the roles of mobile market players, that require new flexible solutions for the allocation of infrastructure and transmission resources to competing operators. The system evolution beyond 5G is then expected to provide new solutions that enable the coexistence of multiple and autonomous decision entities often pursuing conflicting objectives.

This talk will make a link between the technical instruments for network slicing and virtualization on one side and the mathematical models (based on optimization and game theory) for analysing the competition between market players for acquiring the resources and serving their customers.

3 - Cost-Optimal Caching for D2D Networks With User Mobility: Modeling, Analysis, and Computational Approaches
Ghafour Ahani, Tao Deng, Pingzhi Fan, Di Yuan
Caching popular files at user equipments is an effective way to alleviate the burden of the backhaul networks. Generally, popularity-based caching is not a system-wide optimal strategy. Motivated by this observation, we consider optimal caching with the presence of mobility. A cost-optimal caching problem (COCP) for device-to-device networks is modeled, in which the impact of user mobility, cache size, and total number of encoded segments are all taken into account. The hardness of the problem is proved via a reduction from the satisfiability problem. Next, a lower-bounding function of the objective function is derived. By the function, an approximation of COCP (ACOCP) achieving linearization is obtained, which features two advantages. First, the ACOCP approach can use an off-the-shelf integer linear programming algorithm to obtain the global optimal, and it can effectively deliver solutions for small-scale and medium-scale scenarios. Second, and more importantly, based on the ACOCP approach, one can derive a lower bound of global optimum of COCP, thus enabling performance benchmarking of any sub-optimal algorithm. To tackle large scenarios with low complexity, we prove the optimal caching placement of one user can be derived in polynomial time. Then, based on this proof, a mobility aware multi-user algorithm is developed. Simulations verify the effectivenesses of the two approaches by comparing them to the lower bound of global optimum and conventional caching algorithms.

4 - Computing minimum 2-edge-connected Steiner networks in the Euclidean plane
Charl Ras, Marcus Volz, Doreen Thomas, Marcus Brazil, Martin Zachariasen
We present a new exact algorithm for computing minimum 2-edge-connected Steiner networks in the Euclidean plane. The algorithm is based on the GeoSteiner framework for computing minimum Steiner trees in the plane. Several new geometric and topological properties of minimum 2-edge-connected Steiner networks are developed and incorporated into the new algorithm. Comprehensive experimental results have shown our algorithm can reliably compute exact solutions to randomly generated instances with up to 50 terminals—doubling the range of existing exact algorithms.

■ MA-28
Monday, 8:30-10:00 - G102

Portfolio optimization

Stream: Decision Making Modeling and Risk Assessment in the Financial Sector
Invited session
Chair: Cristinca Fulga

1 - Approximation of Value at Risk using models derived from the Cornish-Fisher expansion
Cristinca Fulga

Value at Risk (VaR) has a crucial role in the practice of risk, its accurate and fast determination being essential. Approximations of the VaR value can be obtained by using the models derived from the Cornish-Fisher expansion. Motivated by the drawbacks of these approximating formulas, we propose a new methodology for calculating the VaR of a portfolio based on statistical information that can be retrieved from the population of available feasible portfolios loss distributions.

2 - Behavioral Portfolio Theory Revisited: Lessons Learned from the Field
Andreas Oehler, Matthias Horn

We examine the relation between households' wealth and relative risk aversion (RRA) in two different frameworks: the Behavioral Portfolio Theory (BPT) and Merton's consumption and portfolio choice model (CPCM). For this purpose we use the dataset of the German central bank's (Deutsche Bundesbank) Panel on Household Finances-Survey and apply the BPT to field data for the first time. More specifically, we compute households' high aspiration layer that covers households' risky investments and the wealth available for further risky investments. We show that this implementation of the BPT provides a better fit than the CPCM to explain households' financial risk-taking. This means that households consider rather the easier assessable wealth in their high aspiration layer than their difficult to estimate total wealth in the financial decision making process. However, both models are in favor of decreasing RRA. We furthermore show that households' education and financial literacy hardly improve the fit of either model. Instead, households with the same level of wealth, education, and financial literacy show a different risk-taking behavior in accordance with their self-assessed risk attitude. Our results are robust to changes in the risk-taking measure.

3 - Optimal Portfolio Positioning under Ambiguity: The Multidimensional case.
Hachmi Ben Ameur, Jean-Luc Prigent, Mouna Boujelbène, Emna Triki

This paper provides the optimal financial portfolios in the multidimensional setting when the investor exhibits ambiguity aversion. We consider the Maccheroni et al. (2006) framework which includes both the Gilboa and Schmeidler's (1989) multiple priors preferences and the Hansen and Sargent's (2001) multiplier preferences. We determine the optimal portfolio profile under ambiguity when the investors can invest on various risky assets. Such result extends Ben Ameur and Prigent (2013) when there is only one risky asset. We investigate in particular the CRRA case while introducing an ambiguity index based on the relative entropy criterion. We show in particular how the dependence structure among risky assets and the ambiguity for example on their correlations modify the optimal payoff. Such results have important practical applications in structured portfolio management when investing on multiple financial indices and basket options. Keywords: Portfolio optimization; ambiguity;multiple assets; structured portfolio.

4 - Nested Conditional Value-at-Risk portfolio selection: a model with temporal dependence driven by market-index volatility
Alessandro Staino, Emilio Russo

We propose a multistage stochastic programming model to manage a multi period portfolio allocation problem. The optimization problem, formulated through the nested Conditional Value-at-Risk model, is characterized by an initial allocation date and by other dates where the portfolio may be reallocated. We describe asset log returns through a single-factor model where the driving factor is the market-index log return modeled by a Generalized Auto-regressive Conditional Heteroskedasticity process to take into account the serial dependence usually observed. Under the assumption of zero transaction costs, we propose a backward induction scheme based on cubic spline interpolation to reduce the computational complexity of the problem and find an approximated solution to the optimization problem.

■ MA-30

Monday, 8:30-10:00 - C007

Integrating Machine Learning in Optimization Methods

Stream: Data Science Meets Optimization
Invited session
Chair: *Kevin Tierney*

1 - A Machine Learning Approach to increase Production Plan Stability
Tim Lauer

The trend of digitalization enables new potentials to supply chain management. For a first time, access and connectivity of overall data is available leveraging artificial intelligence based analytical methods. In this context master production planning rarely attracts attention in research. Therefore, this paper provides a first machine learning approach for matching demand and supply for a midterm time horizon, in a volatile, diverse and capacity constrained environment. A framework for measuring planning instability is outlined and a data-driven machine learning approach beyond traditional modelling and simulation predicts a production plan in the upcoming cycle and calculates plan instability subsequently. This may allow to undertake countermeasures in advance dampening the expected instability. The chosen approach combines a random forest classifier and regressor. Moreover, it interrelates the planning periods by updating input feature information according to the preceding period. The approach is applied using the CRISP-DM methodology and validated on real data case study of Infineon Technologies AG, an European semiconductor manufacturer. The analysis results serve as a proof of concept, indicating that in different sections of the planning horizon different input features determine plan instability and that some patterns are easier to learn than others. The evaluation and results foster the basic concept and the application field, but request method extensions for cap

2 - Advancing Project Management through the Integration of Knowledge Graph and Machine Learning Technologies
Nikos Karacapilidis, Nikos Kanakaris, George Kournetas, Vassilis Tampakas

Project Management (PM) is a complex practice that is highly fluid and hard to predict, thus imposing a series of challenges to organizations and experts. At the same time, PM is inherently collaborative and knowledge-intensive; issues to be addressed are characterized by ever-increasing amounts of different types of data and knowledge. We present the first steps of a novel approach towards augmenting the quality of PM-related decision making, which is at the intersection of machine learning and knowledge graph technology. Specifically, we report on the development of a graph-based PM knowledge representation formalism to capture annotations and describe how to manage such knowledge in a graph database. Next, we discuss how our approach leverages structured and unstructured organizational data and knowledge through a meaningful exploitation of diverse Machine Learning algorithms concerning data classification, value prediction, structure discovery, and abnormal behavior detection. Finally, we demonstrate how the proposed solution can assist employees in common PM tasks such as resource assignment, estimation of a task's duration and cost, and prediction about whether deadlines will be met. Our overall approach enables one to uncover hidden relationships, structures and patterns in PM data, and gain valuable insights through testing alternative hypotheses.

3 - Imitation or Understanding? Deep Learning to the Test on Constraint Satisfaction Problems
Andrea Galassi, Michele Lombardi, Paola Mello, Michela Milano

Deep Neural Networks (DNNs) have been shaking the AI scene for their ability to excel at Machine Learning tasks without relying on complex, hand-crafted, features. We probe whether a DNN can learn how to construct solutions of a Constraint Satisfaction Problem, without any explicit symbolic information about the problem structure. Our DNN takes care of the basic step of a generic constructive procedure, i.e. extending a partial solution via a single variable assignment. Both the input and output are described via a fixed-scale, low-level representation that is completely problem-agnostic. As a key design decision, the DNN is trained to replicate the intermediate steps of the construction of feasible solutions, but it is then evaluated in terms of its ability to generate feasible assignments. This is akin to trying to learn how to play a game by watching someone else. Our interest is mainly scientific: if the network succeeds at producing feasible assignments, this would suggest some form of "understanding" of the problem structure and constraints. In principle, the DNN could also be used to solve the problem directly, although other designs may be better suited for this purpose. We report preliminary, but intriguing, results on the N-Queen completion and Partial Latin Square problems: our DNN substantially outperforms random guessing at producing feasible assignments (80% vs 25%), even if it largely fails at the imitation task it was trained for (5% accuracy).

4 - Deep Learning Assisted Heuristic Tree Search
Kevin Tierney, André Hottung

One of the key challenges for operations researchers solving real-world problems is designing and implementing high-quality heuristics to guide their search procedures. Machine learning techniques have only just begun to play a role in operations research approaches, and few approaches exist especially in terms of guiding branching and pruning decisions. We integrate deep neural networks into a heuristic tree search procedure to decide which branch to choose next and to estimate a bound for pruning the search tree of an optimization problem. We call our approach Deep Learning assisted heuristic Tree Search (DLTS) and apply it to a well-known problem from the container terminals literature, the container pre-marshalling problem (CPMP). Our approach is able to learn heuristics customized to the CPMP solely through analyzing existing (near-) optimal solutions to CPMP instances, and applies this knowledge within a heuristic tree search to produce the highest quality heuristic solutions to the CPMP to date.

■ MA-32

Monday, 8:30-10:00 - G109

OR for Disease Treatment

Stream: OR in Life Sciences
Invited session
Chair: *Tomasz Żok*

1 - Improving Medical Decision-Making with a Management Science Game Theory Approach to Liver Transplantation
José Rui Figueira, Francisco Mendonça, Margarida Catalão-Lopes, Rui Tato Marinho

Even though nowadays medicine is necessarily linked with technology, it is still a service involving human interaction, which frequently requires the help of management science tools. Indeed, a medical consultation can be an extremely complex example of human interaction. This is where management science, operations research and in particular game theory may play a key role in helping to improve the results of medical decision-making processes. Game theory is widely used in an immense variety of decision-making studies, but there is little application to health care issues, namely the doctor-patient relationship. This paper uses game theory to model the liver transplantation consultation for patients suffering from Alcoholic Liver Disease. This is a very delicate disease, and patients at its end-stages require special dedication where management science tools are of utmost importance. They may try to deceive doctors, which may lead to bad outcomes. The Nash equilibrium behaviors by doctor and patient are obtained. Results show some health policy and managerial implications on the decision-makers' parameters and on the order of play so as to achieve, for instance, higher rates of patient's cooperation.

2 - A Stochastic Petri Net-Based Model of the Involvement of Interleukin 18 in Atherosclerosis
Agnieszka Rybarczyk, Dorota Formanowicz, Marcin Radom, Piotr Formanowicz

Interleukin 18 (IL-18) is a pro-inflammatory and pro-atherogenic cytokine with pleiotropic properties, which is involved in T and NK cells maturation, production of other inflammatory cytokines and cell adhesion molecules. It plays a significant role in orchestrating the cytokine cascade, accelerates atherosclerosis and influences plaque vulnerability. In order to investigate the influence of IL-18 cytokine on atherosclerosis development, a stochastic Petri net based model has been build and then analyzed. First, MCT-sets and t-clusters have been generated, then knockout and simulation based analyses have been conducted. The application of systems approach that has been used in this research, enabled for an in-depth analysis of the studied phenomenon and allowed to draw valuable biological conclusions.

This research has been partially supported by the National Science Centre (Poland) Grant No. 2012/07/B/ST6/01537.

3 - MINERVA API and Plugin Architecture: New Data Visualization Interfaces for Disease Maps
Piotr Gawron, Marek Ostaszewski, David Hoksza, Reinhard Schneider

Disease maps offer contextualized knowledge on disease mechanisms, which is indispensable for proper interpretation of high volumes of data generated by high throughput experiments, and available via numerous bioinformatics databases. Such interpretations become possible with proper data interfaces that allow to construct multiple information layers on top of disease maps. MINERVA (http://r3lab.uni.lu/web/minerva-website/) is a standalone platform for web-based visual exploration of molecular diagrams.

With the growth of the Disease Maps Community comes the demand for new visualization functionalities. Similarly, additional data interfaces are needed with more and more datasets becoming available, and with the advancing complexity of analysis required for interpretation. To address these needs, the MINERVA platform currently supports the Application Programming Interface (API), enabling automatization of a number of routines that were currently possible only via the user interface. The REST API of MINERVA automates such functionalities as: i) obtain elements and reactions of hosted maps; ii) list drugs, chemicals and miRNA targeting map elements; iii) upload data overlays to a given map. An important extension of the API enables custom JavaScript to interact with the respective MINERVA instance to retrieve its data and modify its visual state. This allows construction of custom plugins for advanced visualization, independent of the core functionality of MINERVA.

■ MA-33

Monday, 8:30-10:00 - Q005

Revenue Management in Airline and Service Systems

Stream: Revenue Management (contributed)
Contributed session
Chair: John Wilson

1 - Airline revenue management: Modelling strategic behaviour using an agent based simulation
Patrick Stokkink, Shadi Sharif Azadeh

With the increase in market transparency, customer behaviour has changed over the last decades. Traditionally, customer segments are based on myopic customer behaviour. Strategic customers learn from their previous experiences and base their buying activity on expectations. In this research we aim to identify how strategic customer behaviour affects the success of revenue management methods. We estimate the utility assigned to different products using two methods in order to approximate the underlying demand. To acquire a good estimation, it is important to correct for spill and recapture effects. The first algorithm to estimate the underlying demand is an expectation-maximization method which uses an iterative procedure to estimate the utility parameters. The second is a new non-parametric approach which, contrary to the first approach, makes no assumptions about the shape of the demand distribution. We construct an agent based simulation model where we distinguish between the two customer segments: myopic and strategic. By using the estimated distributions of demand price and availability and utilities, we estimate the obtained revenue which we compare to a benchmark obtained from the data. We highlight the strength and weaknesses of existing methods, when confronted with strategic behaviour. We highlight the strength and weaknesses of existing methods, when confronted with strategic behaviour.

2 - Data-Driven Alerts in Airline Revenue Management: The Identification of Inaccurate Demand Estimates
Nicola Rennie, Catherine Cleophas, Florian Dost

Most quantity-based airline revenue management systems rely on forecasting expected demand to prepare revenue-optimal capacity allocations. Inaccurate demand forecasts result in non-optimal allocations and hence, hurt revenue. Most airline revenue management systems also allow room for analysts to compare accumulated bookings against forecasts and to intervene, if they deem demand forecasts to be inaccurate. Systematically detecting outliers, where demand differs from expectations due to systematic market shifts, e.g., induced by special events, is an open challenge.

In a set of controlled simulation scenarios, we let demand systematically deviate from the general level. After transforming demand into bookings via a minimal revenue management simulation, we apply a variety of outlier detection techniques to determine whether the number of bookings can be classified as normal or abnormal. The comparison includes a Euclidean distance-based approach, K-means clustering, and tolerance intervals and evaluates the ability to detect genuine outlying demand and false positive rates. We evaluate effects of unexpected demand on revenue, and show that identifying instances of outlier demand and adjusting the forecast in a timely fashion has the potential to increase revenue. Hence, we show that the use of outlier detection techniques as an assistant to revenue management analysts can help to minimise such losses, and we provide best-case-scenario analysis of potential revenue gains.

3 - Competition between Two-Sided Platforms under Demand and Supply Congestion Effects
Fernando Bernstein

This paper explores the impact of competition between platforms in the sharing economy, as in the context of ride-sharing platforms. In particular, we consider competition between two platforms that offer a common service through a set of independent drivers to a market of customers. Each platform sets a price that is charged to customers for obtaining service. A portion of that price is paid to the driver that delivers the service. Customers' and drivers' utilities are sensitive to the payment terms and to congestion in the system. We consider two possible scenarios. Under "single-homing," drivers work through a single platform. Under "multi-homing," drivers deliver service through both platforms. In both scenarios, we study the equilibrium prices that emerge from the competitive interaction between the platforms and explore the outcomes that can arise at equilibrium. We leverage the model to study some practical questions that have received significant press attention. The first involves the issue of surge pricing. The second involves the increasingly common practice of drivers choosing to operate on multiple platforms (multi-homing). We find that raising prices in response to a surge in demand makes customers better off than if platforms were constrained to charge the same prices that would arise under normal demand levels. Also, we find that, while individual drivers may have an incentive to multi-home, all players are worse off when all drivers multi-home.

4 - Optimal pricing in the presence of many ancillary items
John Wilson

In the airline industry, ancillary products such as baggage fees have become very important to the financial health of the industry. Various kinds of ancillary item may be grouped together. For a given price, each grouping of ancillary items has an associated demand function. The problem facing an airline is selecting the prices for the various groupings of ancillary items. We summarise complete optimality results for the case of one ancillary item and general demand functions. We extend results to the case of multiple ancillary items for more restrictive demand functions and derive optimality results.

■ MA-34

Monday, 8:30-10:00 - Q006

Railway Scheduling Problems

Stream: Public Transportation II
Invited session
Chair: *Andrea D'Ariano*
Chair: *Shukai Li*
Chair: *Marcella Samà*

1 - A Lagrangian Relaxation Approach Based on a Time-Space-State Network for Railway Crew Scheduling
Jinchuan Zhang, Ying Wang, Zheming Zhang, Dennis Huisman, Andrea D'Ariano

The crew scheduling problem is an important and difficult problem in railway crew management. In this paper, we focus on the railway crew scheduling problem with time window constraints caused by meal break rules. To solve this optimization problem, a solution method is proposed based on a time-space-state network and Lagrangian relaxation. In this method, the "hard constraints" corresponding to the crew rules are described as the state of vertices in the time-space-state network. Based on the network, this problem is modeled as a network flow model, referred to as an initial model. To break the symmetry and improve the strength of the formulation, five valid inequalities are added. To solve the problem, we relax the coupling constraints by Lagrangian relaxation. The resulting subproblems are shortest path problems in the time-space-state networks. We propose a Lagrangian heuristic to find a feasible solution. Finally, the solution method is tested on real-world instances from an intercity rail line and a regional railway network in China. We discuss the effects of additional valid inequalities and the effects of different length of meal time windows.

2 - Models and algorithms for the real-time train scheduling and routing problem
Marcella Samà, Andrea D'Ariano, Dario Pacciarelli, Marco Pranzo

This talk deals with the real-time train scheduling and routing problem in complex railway net-works. The problem is NP-hard and finding a good quality solution in a short computation time for practical size instances is a very difficult task. In this work we model the problem via an alternative graph formulation and solve it by using a new methodology based on the relaxation of train routing constraints. We assign a nominal routing to each train, formed by common and alternative operations. We call a common operation the traversing of a block section by the train which takes place independently from the actual path chosen. An alternative operation is the shortest path between two common operations and represents alternative portions of a path in the network traversable by the train. Using a so built alternative graph allows to specify implication rules enabling to speed up the computation and to quickly compute good quality lower bounds. This is achieved by solving the corresponding train scheduling problem. Such a lower bound is then used as a first step toward the development of a branch-and-bound algorithm for the overall problem. The decisions taken during the branch-and-bound algorithm refer to selecting the routing of trains and solving the train sequencing and timing decisions generated by these selections. Computational experiments are performed on several railway infra-structures and disturbed traffic situations.

3 - Jointed optimization of train scheduling and maintenance planning on a railway network: a heuristic method using Lagrangian relaxation
Yuan Gao, Chuntian Zhang

Train scheduling and maintenance planning compete for the resources in a railway network. A commonly used way is dealing with maintenance planning first and then train scheduling, or vice versa. In this paper, we develop a three-dimension space-time network, which simultaneously captures the characteristics of the two problems. Based on the space-time network, we formulate an integer programming model, which considers train scheduling and maintenance planning at the same time. In order to solve the model, a heuristic method using Lagrangian relaxation is proposed. Due to the tremendous number of constraints, we start the heuristic method with a small subset of the constraints, and extend the subset with the iterations of Lagrangian relaxation algorithm. Applications on the Chinese railway network show that within acceptable computation time, the heuristic method can find solutions of good quality, the gaps between which and the optimal solutions are all less than 2.5%.

4 - Collaborative optimization for metro train scheduling and train circulation plan combined with passenger flow control strategy
Shukai Li

This work presents a collaborative optimization method for metro train scheduling and train circulation plan combined with passenger control strategy on a bidirectional metro line. The proposed collaborative optimization problem is formulated as a mixed integer nonlinear programming model to realise the trade-off among the utilization of trains, passenger flow control strategy and the number of awaiting passengers at platforms, which is further reformulated into mixed integer linear programming (MILP) model. To handle the complexity of this MILP model, a Lagrangian relaxationbased heuristic approach is designed to decompose the original problem into two small subproblems, which reduces the computational burden of the original problem and can efficiently find a good solution of the train schedule and train circulation plan combined with passenger control strategy.

■ MA-37

Monday, 8:30-10:00 - Q011

Scheduling with Resource Constraints: Interfaces with Related Problems

Stream: Scheduling with Resource Constraints
Invited session
Chair: *Reinhard Bürgy*
Chair: *Dorothea Calmels*

1 - An exact dynamic programming algorithm for the precedence-constrained class sequencing problem
Reinhard Bürgy, Pierre Baptiste, Alain Hertz

We discuss the precedence-constrained class sequencing problem (PCCSP). In scheduling terms, this is a one-machine scheduling problem with precedence constraints and setups with the goal of minimizing the number of setups. From a practical perspective, PCCSP models various scheduling problems in systems where multipurpose processors need retooling or some other type of setup to switch from one operation to another. It appears, for example, in the semiconductor industry, in aircraft disassembly processes and in special traveling salesman applications. PCCSP is also closely related to a loop fusion compiler optimization problem, to a mixed graph coloring problem and to the shortest common supersequence problem. Previous research has shown that PCCSP is difficult to solve from both a theoretical and computational perspective, and only little research has been conducted on computational methods. We propose a dynamic programming algorithm for solving PCCSP exactly. It comprises specialized dominance rules, lower bound computations, propagation algorithms, and heuristics that successfully exploit the problem's structure. Based on extensive numerical experiments, we analyze the algorithm in detail and show that it outperforms mixed-integer programming and constraints programming models.

2 - Employee scheduling with parallel task assignments and complex break time requirements
Martin Gutjahr, Sophie Parragh, Fabien Tricoire

The real-world scheduling problem considered in this paper concerns the assignment of different types of tasks with fixed starting times to a set of employees, whereas multiple tasks may be carried out in parallel, depending on the type of task and the skills of the employee. It also involves shift planning with minimum and maximum shift length constraints, employee dependent availability periods, and complex break scheduling. In addition to legal requirements for total break length and rest time between shifts, problem specific constraints like splitting breaks and preparation time have to be considered. Further constraints include mandatory tasks, consecutive tasks, and limitations for concurrent tasks. The aim is to maximize a weighted sum of the number of assigned tasks weighted by their priorities and negative penalties for assignments to underskilled employees. We propose a large neighborhood search algorithm to solve this problem which relies on a set of tailored destroy and repair operators. Repair operators rank possible insertions of matches into availabilities based on different opportunity cost considerations. Benchmark instances derived from real-world data with over 10000 tasks, over 100 employees, and up to 7 days are solved with the proposed method.

3 - Heuristics for the job sequencing and tool switching problem with non-identical parallel machines and machine-dependent processing and tool switching times
Dorothea Calmels

This work considers the job sequencing and tool switching problem with non-identical parallel machines and machine-dependent processing and tool switching times. This problem is a variation of the uniform job sequencing problem that seeks to minimize the total number of tool switches. This paper proposes several new constructive and improvement heuristics for different objectives, such as minimizing total flow time, minimizing makespan, and minimizing the number of tool switches. The simple and fast constructive approach, step-by-step, assigns jobs to machines based on the current approximated flow time and the current approximated number of tool switches. The proposed improvement concept is an insertion-based method that selects jobs for improvement based on the logic that the job with the least 'net saving value' in terms of tool switches or time should be selected for reinsertion as it may achieve the highest improvement. The performance of the heuristics is analysed with respect to computation time and solution quality for different objectives. The computational experiments show the merits of each heuristic for different objectives. Moreover, it is shown that the heuristics may easily be adapted for different conflicting objectives.

■ MA-38
Monday, 8:30-10:00 - Q012

MCDA and Applications in Engineering and Management

Stream: Multiple Criteria Decision Aid
Invited session
Chair: *Constantin Zopounidis*
Chair: *Michalis Doumpos*
Chair: *Fotios Pasiouras*

1 - Improving marketing bank services: Customer evaluation combining big data and MCDM methodologies
Fernando Mayor-Vitoria, Ana Garcia-Bernabeu

Banking is considered an intensive data generator, but the processing limitation of humans and traditional database systems is a barrier to explore vast quantities of data in order to obtain valuable information. Today's public and private business environments need precise information in real time and big data analysis has appeared as a solution to report about clients' behavior, suppliers, competitors and the whole society. Normally, data analysis has always been understood as a predictive technique in order to guess customer's reactions and future business scenarios. In this sense, the present paper contributes by taking it one step forward, that is to say, from the predictive to the prescriptive analysis and to do so, Multicriteria Decision Making Methods (MCDM) have been incorporated to improve data analysis. Moreover, we identify the indicators which are significant for the marketing bank services in order to create a generic methodology to select the most appropriate potential client. In this context, we apply VIKOR and TOPSIS, which are well known methods among MCDM methodologies, and a numerical example is carried out to show some differences and similarities.

2 - CISEF: A composite index of social, environmental and financial performance
Fotios Pasiouras, Chrysovalantis Gaganis, Menelaos Tasiou

This study employs data envelopment analysis, which uses benefit-of-the-doubt weighting to evaluate the social, economic and financial performance of a sample of large public enterprises around the world. This methodology is especially useful for creating composite indicators as it allows for firm-specific weighting of the different objectives. In additional second-stage analysis, we explore the various driving factors of this index, by regressing it on various formal and informal country-level institutions. Coherent with the issues of a sound Data-Generating-Process (DGP) in such analyses, we make use of a double bootstrap procedure based on the study of Simar and Wilson (2007), permitting us both to make valid inferences and improve the statistical efficiency of the second stage.

3 - Clustering customer satisfaction data with MUSA and Machine Learning
Nikolaos Matsatsinis, Konstantina Miteloudi, Evangelos Grigoroudis, Alkaios Sakellaris

The MUSA method produces a collective assessment model of customer's satisfaction; therefore, the existence of distinguished customer groups with different preference value systems may cause instability in the results. A solution to this problem is the segmentation of the total set of customers into smaller groups according to particular characteristics (age, gender, etc.) that are believed to differentiate their preferences and then, apply the method to each of these sections separately. However, there are cases where this information is not available to analysts and unsupervised learning methods should be used, namely clustering, where grouping is based on the data properties. In this work, a framework is proposed for clustering customer satisfaction data to improve the performance of MUSA method. Synthetic data have been produced from online application "MUSA Data Generator" and MUSA method is applied to the whole set. MUSA's optimization phase extracts the model's overestimation and underestimation errors. Considering that these errors are the distance of each client from the model, one-dimensional clustering is applied, using the algorithm

"Jenks Natural Breaks". Input data are separated and MUSA is applied to each cluster. The model and the metrics AFI and ASI are evaluated for each cluster and their weighted average is calculated, using as a weight the quantitative size of the cluster. The framework has been implemented in Python.

4 - Coordinating Actions of Distributed Decision-Makers
Abhijit Deshmukh

Coordinating and aggregating actions of multiple decision-makers to improve the overall system performance poses several challenges. This paper focuses on two fundamental issues related to such systems, namely distributed coordination and designing incentives. Distributed coordination is framed in the context of task allocation in networked resources. We discuss a set of distributed strategies that lead to an efficient equilibrium solution. The discussion on incentives as a mechanism for coordinating distributed decision-makers is presented in the context of a system where decision-makers have conflicting objectives leading to sub-optimal system-level solutions. We present multi-lateral coordination mechanisms that lead to efficient system-level solutions.

■ MA-39

Monday, 8:30-10:00 - Q014

Data Driven and Robust Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: Izack Cohen

1 - Monitoring With Limited Information
Dan Iancu

We consider a system with an evolving state that can be stopped at any time by a decision maker, yielding a state-dependent reward. The decision maker does not observe the state except for a limited number of monitoring times, which he must choose in conjunction with a suitable stopping policy, to maximize his reward. Dealing with this type of stopping problems, which arise in a variety of applications in project management, healthcare or finance, often requires excessive amounts of data for calibration purposes, and prohibitive computational resources. To overcome these challenges, we propose a robust optimization approach, whereby adaptive uncertainty sets capture the information acquired through monitoring. We consider two versions of the problem–static and dynamic–depending on how the monitoring times are chosen. We show that, under certain conditions, the same worst-case reward is achievable under either static or dynamic monitoring. This allows recovering the optimal dynamic monitoring policy by resolving static versions of the problem. We discuss cases when the static problem becomes tractable, and highlight conditions when monitoring at equi-distant times is optimal.

2 - On determining the optimal proactive-reactive policy for the serial RCPSP with stochastic activity durations
Erik Demeulemeester

When considering the resource-constrained project scheduling problem (RCPSP) with stochastic activity durations, the recent literature mainly considers two different approaches. On the one hand, researchers have focused on proactive and reactive project scheduling, where proactive planning attempts to build a stable project plan that takes the possible disruptions as much as possible into account, while the reactive planning procedures are called every time the disruption changes the baseline schedule such that it cannot be executed anymore as planned. On the other hand, a lot of research has been done on the stochastic RCPSP that introduces scheduling policies that decide at each of the stages of a multi-stage decision process which activities selected from the set of precedence and resource feasible activities have to be started. Recently, Davari and Demeulemeester have introduced an integrated proactive and reactive project scheduling problem for the RCPSP with uncertain durations and developed different Markov Decision Process models to solve this NP-hard problem. This means that not only a good baseline schedule is determined, but also several good continuations in case certain combinations of the activity durations occur that prohibit the baseline schedule or an already adapted schedule from being executed as planned. In this presentation, I will indicate in which cases of the problem truly optimal policies can be constructed and what can be learnt from these policies.

3 - Recent results and insights on robust multi-mode resource constrained project scheduling
Izack Cohen, Noemie Sellam Balouka

We develop a robust optimization approach for the multi-mode resource-constrained project scheduling problem with uncertain activity durations. We use a min-max objective and only assume knowledge about the support of activity durations. The problem is decomposed into two stages and solved using exact and heuristic solution approaches. We consider several types of uncertainty sets in which the level of conservatism can be adjusted. We report on the results and insights from a computational study. We shall present insights about the price of robustness and the performance of the solution approaches.

4 - A Generalized Cutting Plane Algorithm for Robust Optimization with Decision-dependent Uncertainty Sets
Chrysanthos E. Gounaris, Anirudh Subramanyam, Nikolaos H. Lappas

There exist many optimization problems in which the decision-maker can affect the realization of the uncertain parameters (also known as endogenous uncertainty). Such settings can be addressed within the context of a robust optimization framework via the use of decision-dependent uncertainty sets. To that end, we propose a primal branch-and-bound algorithm that generalizes the well-known cutting plane method of Mutapcic and Boyd to the case of decision-dependent uncertainty sets. A comprehensive computational study showcases the advantages of the proposed algorithm over that of existing methods that rely on classical duality-based reformulations.

■ MA-40

Monday, 8:30-10:00 - Q015

OR in the Physical Internet - 1

Stream: OR in the Physical Internet
Invited session
Chair: António Ramos

1 - Two-tier systems in the context of Hyperconnected City Logistics
António Ramos, Bruno Oliveira, Jorge Pinho de Sousa

Two-tier distribution systems have been proposed in the context of City logistics to address the negative externalities of urban freight transport, aiming towards improved efficiency and sustainability, particularly for larger and highly congested urban areas. Hyperconnected City Logistics is a a conceptual framework for more efficient and sustainable urban freight transportation, suggested to embody the synergies between the concepts of City Logistics and of the Physical Internet. Inthispaper, wepresentsomeexamplescollectedfromaliteraturereview of two-tier distribution systems based on mobile depots, which we analyse under the scope of the Hyperconnected City Logistics conceptual framework. Results show that current urban freight distribution systems are rather strict and are far from the open and shared system proposed by the concept of the Physical Internet. Nonetheless, two-tier distribution systems require coordinated and synchronized transportation of loads in a multi-modal transportation network, and some systems have considered the use of standardized unit loads for seamless load transfers between transport modes, an example of an initial step towards goods encapsulation. This work will hopefully contribute for the identification of the current operational characteristics of two-tier distribution systems and of the main challenges towards their full realization as part of the Hyperconnected City Logistics.

2 - Robust Reconfigurable and Hyperconnected Modular Access Hub Networks

Louis Faugère, Benoit Montreuil, Chelsea (Chip) C. White III

This research deals with the dynamic reconfiguration of modular smart locker based access hub networks in the context of first and last mile delivery in Physical Internet oriented hyperconnected parcel logistics systems. Its main contribution is the introduction of a robust dynamic capacity management strategy for modular micro-hub systems. The problem is to define a modular capacity management strategy over the planning horizon that satisfies periodic capacity requirements between each reconfiguration periods while minimizes the costs with a combination of a priori capacity deployment decisions and recovery actions. Possible actions are (1) the relocation of capacity modules and (2) the addition of capacity modules at the beginning of each reconfiguration period. Recovery actions are the pooling of modular capacity from neighboring locations: a location lacking capacity in a requirement scenario can use available capacity from neighboring locations. The presentation first synthesizes insights from the current literature. It then defines the problem, proposes mathematical modeling and illustrates the concept through a case and a sensitivity analysis, highlighting the potential benefits and trade-offs. Finally, it provides directions for future research and innovation.

3 - Strategic Market Deployment Planning of Hyperconnected Fresh Local Supply Chains

Isabella Sanders, Benoit Montreuil, Jiali Zhao

This study introduces a data-driven market deployment planning methodology toward applicability in the context of farm-to-table logistics platforms. These platforms empower food supply chains that are focused on hyperconnectivity, sustainability and transparency following the principles of the Physical Internet. A market deployment process produces a roadmap consisting of sets of markets targeted for deployment at each phase of development of the business. Such deployment must take into consideration both the downstream side of markets, such as urban agglomerations with restaurants, institutions, and households demanding fresh and local food, and the upstream side consisting of farms producing and selling fresh and local food. An integer program optimization model is formulated, that takes in a list of markets and outputs a roadmap optimized for expected profit, allowing companies to achieve market expansion plans under limited resources and managed risks. A use case of the methodology is described, based on a North-American start-up whose platform empowers a fast and efficient transparent food supply chain. It allows restaurants and chefs to order the food to be cooked and offered in their next-day menu directly from farms. By enabling such platforms to succeed in expansion, we can help build local supply chains nationwide, reducing emissions by eliminating long-distance transport and bringing revenue into rural communities helping producers.

4 - Continuous approximation modelling of urban logistics networks and impacts

Hao Jiang, Eric Ballot, Shenle Pan, Farzad Niakan

Urban logistics and the deterioration of urban traffic conditions have gradually drawn peoples' attention. Since the main problem lies on the congestion, it is necessary to design new and innovative urban logistics networks with hubs and different vehicle types. In the study of large and complex problems, the assessment of the performances of different urban logistics schemes and the impacts of the major factors (transportation means, shipment size, vehicle speed, time window, etc.) is the key. The methodology is based on the continuous approach proposed by C. DAGANZO and extended here to vehicle allocation and network optimization under several constraints. Mathematical models (analytical and optimization) are developed to calculate and optimize the cost and environmental impacts of different logistics schemes regarding the vehicle capacity, lead time and shift duration constraints. A case study conducted with the flow and cost data of the distribution process from distribution centers to stores in Bordeaux, France illustrates the methodology. The impacts of different logistics schemes on the financial and environmental performances of the suppliers are evaluated in various distribution schemes. Urban policy restrictions such as limited time window are also investigated.

■ MA-41

Monday, 8:30-10:00 - Q013

Integrated Schedule and Crew Planning

Stream: Public Transportation I

Invited session

Chair: Dennis Huisman

1 - A column generation approach for the driver scheduling problem with staff cars

Shyam Sundar Govindaraja Perumal, Jesper Larsen, Richard Lusby, Morten Riis, Tue Christensen

Given a set of timetabled bus trips, transport companies are faced with the challenge of finding feasible driver schedule that covers all trips and abides by various labor union regulations. The regulations are concerned with providing sufficient breaks for the drivers during the day. Practical limitations in city networks enforce drivers to travel by cars between bus stops to have breaks. Transport companies have a limited number of cars, known as staff cars, which have to be returned to its depot at the end of the day. The simultaneous scheduling of drivers and staff cars is known as the driver scheduling problem with staff cars (DSPSC). It is estimated that the DSPSC accounts for 60% of a company's operational expense, and a column generation approach is proposed that attempts to minimize operational expense. The column generation method iterates between a master problem, a subproblem for generating driver variables and a subproblem for generating staff car variables. The subproblem related to the drivers is formulated as a resource constrained shortest path problem, which is solved by a dynamic programming approach. The proposed method is tested on eight real-life instances from seven Northern European companies. A comparison with a state-of-the-art mixed integer programming solver and an adaptive large neighborhood search heuristic indicate that the column generation method provides improved solutions for six instances and the average improvement is 1.45%.

2 - A Column Generation Approach for the Crew Replanning Problem

Thomas Breugem, Twan Dollevoet, Dennis Huisman

In railway operations, the crew schedules often have to be adjusted shortly before the actual day of operations, to allow for, e.g., planned maintenance. Such maintenance activities lead to blocked tracks, for example, and hence some crew schedules might no longer be feasible, as certain trips can no longer be performed. As a result, new crew schedules have to be constructed, which are feasible for the new situation, and cover as much work as possible. Furthermore, the new schedules should not deviate too much from the original plan. Currently these new schedules are constructed on a day-to-day basis, possibly leading to a loss of overall efficiency. We introduce the Crew Replanning problem, where the goal is to reschedule the crew over a period of multiple days, thereby adjusting both the duties and the rosters. We propose a solution method combining column generation with Lagrangian relaxation, and apply this method to practical cases from Netherlands Railways.

3 - An Iterative Approach for Integrated Planning in Public Transportation

Alexander Schiewe, Philine Schiewe

Optimization in public transport planning is an important topic of ongoing research. Traditionally, the planning process is separated hierarchically into several stages, e.g. line planning, timetabling and vehicle scheduling. Recently, integrated public transport planning, i.e., optimizing several of the planning stages simultaneously, has gained in importance as this can improve the solution quality immensely. However, since the resulting integrated problems are computationally challenging for close-to real-world instances, heuristic solutions are commonly used. We here introduce a new iterative approach for re-optimizing an existing public transport system. For this, two of the three planning stages line planning, timetabling and vehicle scheduling are fixed while the remaining one is re-optimized. To model the re-optimization, traditional approaches do not suffice and therefore new optimization problems need to be defined. We model these problems and propose solution algorithms for each stage which are theoretically analyzed. Additionally, convergence of the proposed iterative approach is discussed theoretically and computationally tested on a benchmark case study and a close-to real-world data set.

■ MA-42

Monday, 8:30-10:00 - Q113

OR application for MaaS I

Stream: Transportation
Invited session
Chair: *Danijela Tuljak-Suban*

1 - Solving a static bike repositioning problem using the artificial bee colony algorithm

Yue Wang, Wai Yuen Szeto

This study tackled a static Bike Repositioning Problem (BRP) with broken bikes. It aims to design the route and corresponding loading/unloading quantities for the reposition vehicle to satisfy the demands of all the stations in a bike sharing system. The objective is to minimize the CO2 emissions of the vehicle during repositioning. An artificial bee colony (ABC) algorithm with adaptive neighborhood operators is developed to search for the vehicle route, incorporating a newly introduced evaluation method. This evaluation method is designed for adjusting the loading/unloading quantities for the routing problem that allows for multiple visits and has a vehicle load related objective function. The performance of the proposed algorithm on the BRP is evaluated in different instances having 10-300 stations. The results show that the proposed algorithm can find the optimal solutions for small-sized networks within a much shorter time than the exact method. In addition, for the instances that the exact method cannot provide the optimal solution within the time limit, the proposed method outperforms both the genetic algorithm and the memetic algorithm. The result confirms the ability of the ABC algorithm in solving this type of problems.

2 - Approximate dynamic programming for multi-period taxi dispatching

Felix Götzinger, Anne Meyer, Martin Pouls

300,000 to 500,000 cab rides arise every day in New York. Conducted by roughly 30,000 taxi drivers and mostly allocated by taxi dispatchers. To allocate and to reposition the taxis, the expected value of future positions needs to be considered. The target is to create a method, which provides decision support in real-time and incorporates stochastic information. In this talk we define and solve the taxi dispatching problem as a stochastic dynamic resource allocation problem (SDRAP). Due to the large number of states, results, and actions we use an approximate dynamic programming approach (ADP). Our solution strategy is sampling-based and solves network flow problems as LP for each discrete point in time. Using the duals of the LP solutions, we estimate concave value functions via reinforcement learning techniques within the simulation to predict future revenue and incorporate these functions into the model. We perform evaluations on historical taxi trip records provided by the New York City Taxi and Limousine Commission. In our experiments, we compare different value function approximations, parameter settings and instance sizes. Compared to myopic policies, our method leads to an increase of roughly 60% in revenue due to a higher utilization of cabs and roughly 90% less waiting cabs. In addition, we estimate well performing value functions and visualize them with heat maps. All in all, the decision support can be realized in real-time for realistic taxi data instances.

3 - Analyzing the delay sensitivity of an integrated mobility system

Yves Molenbruch, Kris Braekers

In many Western countries, governments are currently implementing an innovative demand-driven mobility policy. Providers of collective door-to-door transport, called dial-a-ride services, are increasingly invoked to replace unprofitable public transport in rural areas. This requires an integrated mobility system in which a user's trip may consist of a combination of dial-a-ride services and regular public transport. To optimally integrate both systems from an operational point of view, dial-a-ride providers need to solve a challenging routing problem, in which their flexible vehicle routes should be synchronized to the timetables of the remaining public transport services. However, the practical feasibility of such an integrated mobility system strongly depends on the reliability of the transfers. Dial-a-ride providers should adequately respond to structural or occasional delays of the public transport. Whenever such delays are likely to cause broken connections or violated quality requirements, the provider needs to make real-time adaptations to its routes and schedules, restoring feasibility at an additional cost. The objective of this work is to quantify the sensitivity of integrated routing solutions with respect to delays on the public transport network. To this end, the travel times of the public transport are modeled as stochastic, time-dependent travel times. The impact of different types and extents of delays on the operational efficiency of the system is quantified.

4 - A fuzzy hybrid MCDM method for bike-sharing network definition

Danijela Tuljak-Suban, Valter Suban

The traffic congestion growth in cities areas and environmental awareness increase have contributed to rise popularity of bike-share systems in cities around the world. Despite the actuality of the problem, there are only few articles deals with the bike-share systems definition and evaluation. In the literature, bike-share services are defined and evaluated using MCDM models, generally based on criteria related to: the urban spatial characteristics, transportation network/traffic and population density. In addition, detected models solve and consider just local situations. Comparison between bike-sharing and car-sharing models highlights that in case of bike sharing: investment costs, revenue and repositioning restrictions are not considered. So, those models can be efficiently used only if the bike flow and usage are homogeneous in the entire network. The most used methods are: ANP, DEMETAL, VIKOR and TOPSIS. Those methods are often associated to fuzzy reasoning, since used criteria are not all quantitative. On the base of the literature review, the paper proposes a framework that is an update of existing methods for the definition of the bike-sharing network and is based on the spatial characteristics and transportation network but also consider the repositioning of the bikes. The inputs in the model are the bike-share stations with their characteristic the outputs of the model are proposed bike-sharing stations ranked by appropriateness.

■ MA-46

Monday, 8:30-10:00 - L243

Computational Methods in Games and Applications

Stream: Variational analysis, games and intertwined optimization problems
Invited session
Chair: *Laura Rosa Maria Scrimali*

1 - Robustness and semi-infinite programming via generalized Nash games
Giancarlo Bigi, Simone Sagratella

One way to deal with uncertainty in optimization problems relies on the introduction of uncertainty sets for the data. This allows considering solutions that are feasible for any realization of the data while taking into account the worst-case for the objective as well. Problems such as portfolio selction and production planning are exploited to address how to formulate robust counterparts of optimization problems as semi-infinite programs (shortly SIPs), i.e., optimization problems with infinitely many constraints. In turn, SIPs share some similarities with Generalized Nash games (shortly GNEPs) that lead to meaningful connections. Indeed, SIPs can be reformulated as GNEPs with a peculiar structure under some mild assumptions. Pairing this structure with a suitable partial penalization scheme for GNEPs leads to a class of solution methods for SIPs that are based on a sequence of saddlepoint problems. Any converging algorithm for the saddlepoint problem provides the basic tool to perform the penalty updating scheme. In particular, a projected subgradient method for nonsmooth optimization and a subgradient method for saddlepoints are adapted to our framework and the convergence of the resulting algorithms is shown. A comparison between the two algorithms is outlined as well.

2 - Data driven coordinated replenishment solution
Anne Porte, Dario Bauso

Motivated by a case study on a multi-item two-echelon for two perishable edible goods with one warehouse and multiple retailers in the region of Groningen, we deal with the analysis and design of a new business model for data-driven coordinated replenishment.

First, we develop a logistic network whereby the nodes represent storage facilities and the arcs describe either transportation links or production/demand units. To address uncertain demand, historical demand data are used to build and calibrate a forecasting model based on linear regression and which includes seasonality and trend. Then, we formulate and solve a stochastic optimization problem which takes as input the forecasted values, and provides as output the optimal flows in each arc. The cost to minimize includes a major fixed cost associated with each replenishment and a minor cost associated with an item involved in the replenishment. To quantify the benefit from coordination, a coalitional game with transferable utilities is developed in which the retailers who agree on joint replenishment can be seen as a coalition. Finally, we address issues related to the stability of the coalition in response to specific allocation policies.

Fiestras-Janeiro, M. G., García-Jurado (2011). Cooperative games and cost allocation problems. Top, 19(1), 1-22. Silver, E. A., Pyke, D. F., & Thomas, D. J. (2016). Inventory and production management in supply chains. CRC Press.

3 - An extension of Braess' paradox to transportation network cooperative games
Mauro Passacantando, Giorgio Gnecco, Yuval Hadas, Marcello Sanguineti

Braess' paradox is a classical result in the theory of congestion games. It highlights the reason why the insertion of a resource in a network may, in some cases, deteriorate - instead of improving - the global network performance. This is typically explained using the theory of noncooperative games when several resources are added to the network. However, this approach does not allow to quantify the average marginal contribution of each resource to the global network performance. This suggests the development of a cooperative version of Braess' paradox, in which the players are the resources (e.g., the arcs in the network), and the importance of each player is measured by its Shapley value. In this presentation, we describe some preliminary results obtained in an extension of Braess' paradox to the case of transportation network cooperative (TNc) games, which are a particular class of transferable utility games. We express the characteristic function of a TNc game in terms of a suitable measure of congestion on the subgraphs associated with subsets of players of the game. For each subgraph, this measure is determined by solving an instance of the user equilibrium problem. Numerical results show that, for our choice of the characteristic function, some resources may have negative Shapley value. Hence, on average, their removal increases the global network performance.

4 - A new interior point algorithm for the Fisher type market exchange model
Anita Varga, Tibor Illés, Marianna E.-Nagy

The Fisher type market exchange model is a special case of the Arrow-Debreu type market exchange model. In this case, the players are divided into two groups, consumers and producers. Producers sell their products for money, and the consumers have an initial amount of money that they can use to buy a bundle of goods which maximizes their utility functions.

In this talk, we introduce a new interior point algorithm to solve the weighted analytic center problem discussed by Yinyu Ye in his article in 2006, therefore we show a new way to find the solution of the Fisher type linear and Leontief market exchange models. We also present our new numerical results.

■ MA-47

Monday, 8:30-10:00 - L247

Behavioural OR general papers

Stream: Behavioural OR
Invited session
Chair: L. Alberto Franco

1 - Studying behaviour in OR interventions: A review
L. Alberto Franco, Raimo P. Hämäläinen, Etienne Rouwette, Ilkka Leppanen

In this talk we present an overview of the rapidly growing body of empirical research that examines the impact of behaviour in interventions that use OR approaches, methods and tools to support decision making. A survey of the relevant literature spanning 30 years identified four types of empirical studies. Each type varies in how it characterises behaviour (determinist or voluntarist), and the research methods it employs (variance or process) to examine behavioural phenomena within the intervention. We argue that each type can only offer a partial understanding of the role and impact of behaviour in OR interventions, and that taking the insights produced by all four study types together offers a richer understanding of the behavioural dimension than any one type can offer by itself. We will offer some suggestions for the further development of the behavioural agenda related to OR intervention research.

2 - Trajectories of praxis: an empirical behavioural OR study
Sonya Crowe, Martin Utley

There has been a recent renewal of interest in research about the role and impact of behaviour on the effectiveness of OR. Healthcare is one thematic area that is ripe for the attention of such studies given the importance of the issues, the potential amenability of healthcare problems to OR approaches, and yet the relatively poor impact of OR in influencing decision-making to date. To this end, we conducted an empirical behavioural OR study of non-technical influences on the uptake of academic OR in healthcare. We elicited the perspectives and experiences of OR practitioners working in academic healthcare OR using social science approaches to data collection and analysis. Our findings contribute useful insights regarding the OR actor and OR praxis dimensions of Franco & Hämäläinen's organising framework for behavioural OR studies, and the interactions between them. In particular, our work highlights the importance of considering trajectories of praxis beyond individual projects / interventions. We will present our work in relation to current discourses in behavioural OR, separating the findings specific to healthcare and those that might translate to academic OR practitioners working in other fields.

3 - Behavioral OR from a Swedish military OA perspective
Ida Johansson

Military Operations Analysts, OA, pose a highly valued resource within the military headquarter of the Swedish Armed Forces, providing analysis and decision support. OA are exclusively provided by the Swedish Defence Research Agency, FOI. What makes OA unique to the military organization is their perceived outside perspective and objectivity, their collective organizational memory and their positions at all management levels, giving informal channels in the otherwise highly hierarchic organization.

Characterizing to Swedish military OA, compared to those of NATO and other partner organizations and countries, is the focus on soft OA, the relatively small military headquarter and OA organizations and the everyday access to the client, as OA work together with the military personnel in the same facilities.

The workplace includes organizational and structural limitations as well as advantages. In this presentation, individual experiences from working as an OA at the tactical level will be shared. The conditions for using OA methods are limited by a high level of individual work amongst officers due to low staffing, high staff rotation and a partly fragmented organization, with the result that OA are often let into the working process too late to help structuring and formulating problems. The introduction of OA methods is facilitated by "teaming up" with officers, persistency as well situation awareness. Observations are analyzed from an organizational perspective.

4 - Widening the OR competences: Systems Intelligence
Raimo P. Hämäläinen

Today there are frequent calls to widen the skillset in all professions to include soft capabilities such as emotional and social intelligence. The recent article by Hämäläinen et al. (2018) discusses Systems Intelligence (SI), a general soft competence related to one's ability to succeed in wholes, i.e., in systemic settings which are complex and challenging due to both technical and people dynamics. The article suggests that the SI competence needs to be included in the skillset of engineers in a modern society. I take this same idea into the field of OR. Behavioural OR is interested in the effects people have on the OR process and thus we should also understand the competences required of a behaviourally sensitive OR practitioner. OR deals with systemic problems and in problem solving one also needs to pay special emphasis on social systems and people skills. The SI competence can be measured and developed and my suggestion is that we should include it in the skillset of OR professionals. This would complement the OR skills suggested earlier in the literature by bringing social systems and people engagement into the focus. Ref: R.P. Hämäläinen, E. Saarinen and J. Törmänen: Systems Intelligence - a Core Competence for Next Generation Engineers?, in Proc. of the 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE) ,Wollongong, Australia, pp. 641-644.

■ MA-48

Monday, 8:30-10:00 - L248

Environment and Finance I

Stream: Applications of Dynamical Models
Invited session
Chair: Chung-Huey Wu

1 - Managing landscapes to mitigate the hazard of wildfires while conserving ecosystems
John Hearne

Developing a schedule for prescribed burning in a landscape is a challenge for landscape managers. In addition to reducing the hazard of wildfire, various other constraints must be considered. To help deal with this problem we present a spatially explicit, multi-period optimisation model. It will be demonstrated that the model can be solved to yield a plan to generate a dynamic landscape mosaic that optimally fragments the hazardous fuel continuum while satisfying ecosystem constraints. We demonstrate that such a multi-period plan for fuel management is superior to a myopic strategy despite the occurrence of unplanned fires. We also show that a range of habitat quality values can be achieved without compromising the optimal fuel reduction objective. This suggests that fuel management plans should also strive to optimise habitat quality. We illustrate how our model can be used to achieve this even in the special case where a faunal species requires mature habitat that is also hazardous from a wildfire perspective. Typical Australian heathland landscapes are used to illustrate the model but the approach can be implemented to prioritize treatments in any fire-prone landscape where preserving habitat is a critical constraint.

2 - Incorporating funding flexibility and liquidity into investment decisions of land trusts to seize emerging conservation opportunities
Chung-Huey Wu, Mathew Hardy, Cindy Hauser, Michael McCarthy

Conservation revolving funds routinely purchase land properties to protect their environmental values, and then resell them to conservation-minded buyers with permanent conservation covenants attached. Fast resale of purchased properties to replenish the fund is key to revolving fund performance, especially in acquiring emerging valuable properties before they go off the market. Here we study how to select properties to purchase in a degrading landscape to stop losses in conservation values. We use mixed integer programming to select initially available properties that produce optimal expected resale income for buying newly emerged properties at a second time step. This optimal strategy out-performs ranking methods based only on cost-effectiveness where capitals can be locked in properties with slow resale. Our resale-explicit approach are especially beneficial for small funds that can only afford a few properties. We suggest fund managers to make investment decisions that balance early conservation benefits with future financial liquidity to seize valuable opportunities that emerge over time.

3 - Industrial eco-efficiency performance and dynamics in Europe. The existence of technological spillovers within a metafrontier framework
Eirini Stergiou, Kostas Kounetas

EU policies concerning global warming have been outspread the last few decades as air pollution consists the largest environmental problem. Initiatives for air quality's improvement has been added in the agenda of environmental directives on the grounds that the prolonged economic growth intensified the environmental issues rapidly and made the link that connects them even more solid. The manufacturing production process is one of the responsible sources of the poor environmental performance as undesirable outputs are produced simultaneously with the produced output. We model the eco-efficiency performance under a meta-frontier framework for 14 industries from the manufacturing sector from 27 European countries over the 1995-2011 period. The utilization of NOx, SOx, CO_2, CH_4, N_2O, CO, NMVOC and NH_3 as undesirable outputs and GVA as the desirable help us to understand better this concept. In the first stage, we estimate the efficiency using the conventional Directional Distance Function (DDF) as well as the non-radial DDF approach by embodying slacks under different technology regimes to examine if technological heterogeneity could influence the eco-efficiency scores. In the second stage, we investigate the existence of convergence and distribution dynamics on different types of eco-efficiency and technology gap. The estimated results will indicate whether industries will move towards the meta-technology frontier and if opportunities for abatement procedures are present.

4 - Energy transition planning in manufacturing firms: An integrated model addressing economic and environmental issues
Ehsan Izadpanahi, Tiru Arthanari

Energy transition towards low-carbon energies is a big challenge in different industries due to its complexities and the huge capital investment needed. In different countries various financial incentives / facilities are usually provided for industries to enhance their energy basket while they are also pushed towards clean energies through some environmental regulatory measures like, caps on carbon emission. Manufacturers therefore need an efficient energy transition planning to improve their energy basket. In this regards, we find Capacity Expansion Planning (CEP) models (as) an appropriate context in which operational decisions in manufacturing firms can be integrated to energy transition decisions. Accordingly, a mixed integer linear programming (MILP) model is developed to integrate energy planning, capacity planning, energy investment planning and energy transition planning while focusing on economic and environmental aspects of the energy investment. Since financial facilities are often long-term and their repayments are monthly, integration of strategic and tactical planning horizons is needed. In this paper, we carry out loan modelling integrating two planning horizons. This is a two phase research, the first phase achieves the integrated model and in the second phase appropriate optimization strategy and solving the model is planned. Finally, the model's sensitivity to variations in different parameters will be assessed.

■ MA-49

Monday, 8:30-10:00 - L249

Control Theory and system dynamics

Stream: Control Theory and System Dynamics (contributed)
Contributed session
Chair: Nikolas Tsantas

1 - Aircraft climb trajectory optimization using optimal control
Hasnae Kasmi

The current air traffic management system, based on a rigid airspace and ATS route structure with predefined way points, airways and procedures is evolving to a new paradigm called Trajectory Based Operations which allows a greater freedom for the airlines to plan their trajectories. In this context, trajectory optimization provides to airlines an opportunity to reduce the flight costs. A typical approach to deal with this problem is optimal control. Different methods can be used to solve such a problem which can be split into two basic categories: direct and indirect methods. In this paper, we focus on direct collocation methods. We wish to optimize speed and thrust laws during the climb phase between an initial point where the aircraft is equilibrated and a cruise point characterized by its altitude and Mach number. The criterium to minimize is the flight cost. The dynamic of this problem is deduced from a classical point-mass model composed of simplified aerodynamic polar and propulsive characteristics. The original infinite-dimensional and continuous optimization problem is then discretized and transformed into a nonlinear programming problem involving a finite set of variables. The numerical solution is obtained by using an interior-point solver. This work is the first step of a more general study that aims at applying optimal control techniques to the global optimization of the complete (multi-phase) mission using Airbus's reference performance model.

2 - A state space approach for studying the impact of Internet of Things on bullwhip effect
Christos Papanagnou

Internet of Things (IoT) provides better connectivity among supply chain participants by providing additional information and making, which may be used for better replenishment policies and inventory control. As information transmission lag still exists in supply chains, even when state-of-the-art RFID and IoT technologies exist, organisations seek solutions to leverage the existing technology and improve the overall supply chain performance. In this research work, a novel 3-node supply chain model is presented (Supplier-Manufacturer-Retailer), where base-stock replenishment policies are modelled by means of a proportional controller and IoT is utilised among supply chain nodes.

A stochastic state-space model is derived to capture the inventory and product quantity changes as a function of (i) information derived from IoT and (ii) proportional controller. Customer demand is represented by a stochastic sequence while the model is analysed under stationarity conditions with the aid of a covariance matrix. The model provides useful insights on how IoT is linked with replenishment policies while an optimisation method is introduced to study the impact of IoT on inventory management. This allows measuring and alleviating the bullwhip effect subject to fluctuations in inventory. The model proposed can solve the information asymmetry problem in supply chain efficiency and can help organisations to develop a global supply chain management strategy based on IoT technology.

3 - Dynamics of systems in the management of inventories based on JIT philosophy
Diego Andrés Carreño Dueñas, Erika Tatiana Ruíz Orjuela

The management inventories is a transverse activity in the supply chain, which is one of the most complex logistical aspects of any company. The determination of inventory levels is associated with the service levels for production and customers.

The current investigation seeks to build a dynamic model that allows the optimization of inventory management using the JIT philosophy, through the dynamics of systems as a methodological tool that allows knowing the behavior of variables according to their relationships taking into account their causality and feedback. Likewise, the methodology allows defining, integrating and quantitatively formulating the multiple activities associated with the problem of inventories such as the relationship between production and sales, with the purpose of integrating the inventories in the delivery plans to provide the products at the time exact, in the exact amount and with the requirements specified.

The formulation of the mathematical model that supports the dynamic model must be a process based on the behavior of the inventory, bearing in mind the most important theoretical concepts related to inventory management and control. In the study, comparisons are made with different simulation scenarios and it is demonstrated that with variable interaction formulations, results can be be obtained that can solve common problems associated with inventory management, such as replenishment points and optimal order quantity under a JIT approach.

4 - Elaboration on the multivariate non-homogeneous Markov manpower system under various conditions and properties
Nikolas Tsantas, Andreas Georgiou, Vasileios Dimitriou

In this work we build upon the theory of the non-homogeneous multivariate Markov manpower system. We suggest a model, which takes into account the divisions and departments in an organization considering intra and inter-department transitions. By introducing cost objectives we can investigate control scenarios regarding recruitment or allocation policies. In addition we elaborate on functional forms by studying the system's equilibrium behavior under various conditions and properties.

■ MA-50

Monday, 8:30-10:00 - Mason Hayes & Curran

Pricing, investment, and sustainability

Stream: Operations/Marketing Interface
Invited session
Chair: Linda (Xiaowei) Zhu

1 - Investment Timing and Capacity Decisions with Time-to-Build in a Duopoly Market
Haejun Jeon

We investigate firms' optimal investment timing and capacity decisions in the presence of time-to-build and competition. Due to the uncertainty in time-to-build, the product of the leader who makes the first investment might enter the market later than that of the follower. We show that a firm dominated by investment lags can become a leader and that the leader's optimal capacity increases in the size of the dominated firm's lags, even when the dominated firm becomes the leader. This result is consistent with the electric vehicles market, in which a relatively new firm lacking experience in mass production makes an aggressive investment, while the biggest car makers capable of mass production with shorter lags are timing their investment. With a welfare-maximizing policy, however, the dominant firm always becomes the leader. Compared to investments according to the welfare-maximizing policy, the leader and follower's investment choices in the market are inefficiently late and early, respectively. The welfare-maximizing capacities of both the leader and the follower are much higher than those determined in the market, but the difference is more pronounced in the leader's capacity. There is a significant loss of social welfare resulting from the dominated firm becoming the leader, and the loss increases as the dominated firm's time-to-build increases.

2 - An analysis of the dynamic price-quality relationship
József Vörös

Maximizing profit, we develop a dynamic model in which demand depends on both price and quality. In part, quality can be increased by investing into development processes and the value of the accumulated quality knowledge is incorporated into the model. It is pointed out that this salvage value may have large impact on the solution and fundamentally may influence the dynamics of the quality improvement process. The quality dynamics may have both increasing and decreasing impact on price, and besides known factors the influence of the Hamiltonian is identified. We can observe also, that improving operational efficiency softens price increase while quality increases.

3 - Optimal Green Product's Pricing and Level of Sustainability in Supply Chains: Effects of Information and Coordination
Linda (Xiaowei) Zhu

We analytically study a supply chain model where a manufacturer produces a green product and sells it to the end consumers through a retailer. We formulate the analytical model as a Stackelberg game. In the game, the manufacturer is the Stackelberg leader who decides the wholesale price and product sustainability level, and the retailer is the follower who reacts by setting the retail price. After deriving the Stackelberg equilibrium of the wholesale price, the product sustainability level, and the retail price in the closed form expressions, we compare these analytical results and also conduct numerical experiments to analyze the manufacturer's, the retailer's, and the whole supply chain's performances. We derive and compare the equilibrium under three business scenarios, including Decentralized Supply Chain with Non-information Sharing (Scenario N), Decentralized Supply Chain with Information Sharing (Scenario I), and Centralized Supply Chain (Scenario C). We give managerial suggestions to the manufacturer and the retailer on how to promote the green products and achieve organizational sustainability goals. We also analytically illustrate how to coordinate the channel, and highlight the crucial role played by information in the green product supply chain.

4 - The "price cartel" game in the Japanese mobile market
Norihiro Hayakawa, Yasufumi Saruwatari

A cartel in price between mobile network operators (MNOs) in Japan is treated, and a mechanism under the cartel is derived in this paper. It is well-known that in the Japanese mobile telecommunications market, every MNO delivers its own mobile network service combined with cellular devices, and employs the "enclosure strategy" for customers in order to protect customer's transfer. In addition, it looks as if MNOs form a "price cartel" agreement - the basic monthly charge for the mobile network service is almost the same among MNOs. Through the "cooperative oligopoly," it has lost the market liquidity. The Japanese government, therefore, claims that their improvement in their business practices.

We propose a Cournot(-type) competition game, where the cooperative action done by every MNO is realized. The findings show that a deceleration of the market growth is a primary factor in MNOs' "price cartel." MNOs keep "price cartel" unintentionally in the mature market, and this is Nash equilibria in the game. On the other hand, when the market is growing, MNOs steal a march on the others and break the cartel. The results can explain the MNOs' market behavior in the Japanese mobile market. "Price cartel" in infrastructure markets is a major political issue in Japan, and the government is offering new price regulations. Our results imply that the key success factor in breaking "price cartel" would be the coexistence of price down and market growth.

■ MA-51
Monday, 8:30-10:00 - William Fry

Dynamic Models

Stream: Dynamical Systems and Mathematical Modelling in OR
Invited session
Chair: *Yukihiro Maruyama*

1 - Non-deterministic sequential decision process and its application to tree knapsack problems
Yukihiro Maruyama

This paper clarifies the relation between a given non-deterministic discrete decision process(nd-ddp) and a subclass of non-deterministic monotone sequential decision process (nd-msdp); the functional equation of non-deterministic dynamic programming is obtainable for the nd-msdp. The strong representation by the subclass of nd-msdp provides a necessary and sufficient condition for the existence of it with the same set of feasible policies and the same cost value for every feasible policy as the given process nd-ddp. Further, the strong representation is applied to non-deterministic tree knapsack problems and some algorithm to solve the problems will be given.

2 - Finite Horizon Risk-Sensitive Markov Decision under Risk Constraints: Coherent Risk Measures Derived from Risk Averse Utility
Yuji Yoshida

Finite horizon Markov decision making with risk constraints is discussed from the viewpoint of coherent risk measures. Weighted sums of immediate rewards are described by Markov strategies. In this talk, risk-sensitive expected terminal rewards are approximated by weighted average value-at-risks, which are the best coherent risk measures derived from decision maker's risk averse utility. The risk constraints for immediate reward at each stage are also estimated by coherent risk measures. These coherent risk measures are represented by weighted average value-at-risks which can inherit the risk averse property of the decision maker's utility function as weighting by risk spectrum. To find feasible regions of the constraints, a risk-minimizing problem at each stage is firstly discussed by mathematical programming. Next risk-sensitive expected terminal rewards are investigated under the feasible coherent risk constraints. Regarding this finite horizon decision problem, it is difficult to use dynamic programming and so we solve it as a multi-parameter optimization problem. A few numerical examples are given to understand the results in comparison with risk averse utility functions and the corresponding risk spectra.

3 - Banks as Tanks
Isaac Sonin

We present a simple model of clearing in financial networks in continuous time. In the model, banks (firms, agents) are represented as tanks (reservoirs) with liquid (money) flowing in and out. This approach provides a simple recursive solution to a classical static model of financial clearing introduced by Eisenberg and Noe (2001). It is also suggests a practical mechanism of simultaneous payments. The dynamic structure of our model helps to answer other related questions and, potentially, opens the way to handle more complicated dynamic financial networks. Also, our approach provides a useful tool for solving nonlinear equations involving linear system and max min operations similar to the Bellman equation for the optimal stopping of Markov chains and other optimization problems. References Eisenberg, L., Noe, T. (2001). Systemic Risk in Financial Systems. Management Science, 47(2), 236-249. Bitar, K., Kabanov, Yu., Mokbel, R. (2017, 2018). Clearing in Financial Networks, Theory of Prob. and its Appl., 62(2), 252-277. Sonin, I., Sonin, K., (2017). Banks as Tanks: A Continuous-Time Model of Financial Clearing, arXiv:1705.05943

4 - An attack-and-defense game on a network with multiple start nodes and destination nodes for attackers
Ryusuke Hohzaki

This report deals with an attack-and-defense game, where attackers move along some routes from start nodes to destination nodes on a combat network and defenders are deployed to intercept the attackers on arcs. The game has the number of surviving attackers reaching the destination nodes as its zero-sum payoff, which the attackers desire to maximize and the defenders want to minimize. Each group of attackers chooses a route to move along and the defenders make a deployment plan on arcs. Initial numbers of the attackers and the defenders are given but they decrease through conflicts between the attackers going and the defenders deployed on some arcs. The attrition of the attackers and the defenders is ruled by the so-called Lanchester's linear law. We model the attack-and-defense game played on a network and propose a mathematical programming formulation to derive its equilibrium. The equilibrium teaches us a rational selection of attacker's routes to save their lives, a rational deployment for the defenders to intercept the attackers in an effective manner and a relationship between the optimal strategies of both players. Our methodology could be applied to practical examples of the so-called network interdiction game, which have been analyzed in order to interdict malicious invaders from damaging valuable networks, e.g. telecommunication networks, infrastructure networks, infection networks and traffic networks.

Monday, 10:30-12:00

■ MB-01

Monday, 10:30-12:00 - O'Reilly Hall

Leon Petrosjan

Stream: Tutorials
Tutorial session
Chair: Milos Kopa

1 - Time-Consistency Problem in Control Theory and Dynamic Games
Leon Petrosjan

The solution of dynamic optimization problem is time-consistent if the use of this solution policy to a sub problem with a later starting time and state brought about by prior optimal behavior would remain optimal in the sub problem. In classical optimization problems solvable with dynamic programming technique the optimal solution is time-consistent. In multicriterial control problems Pareto-optimal solutions also are time-consistent, but different selection procedures for choosing of one special solution from the set of all Pareto-optimal solutions are in general time-inconsistent (for example the NB-solution). In differential and dynamic games Nash equilibrium is a time-consistent solution, but practical all solution concepts taken from classical one-shot cooperative game theory are time inconsistent (core, Shapley value, nucleolus). We present examples of time-consistent and time-inconsistent solution concepts in mulicriterial control and dynamic games and propose refinement procedures to make solutions time-consistent.

■ MB-03

Monday, 10:30-12:00 - Q106

fast and furious

Stream: Practice of OR (Making an Impact)
Tutorial session
Chair: Ruth Kaufman

1 - Fast and furious: lightning talks
Ruth Kaufman

At a EURO conference there is an enormous amount of interesting material that any one person can only see a small fraction of. This session will help boost that fraction. Each presenter will have just 5 minutes to present a lightning talk: a maximum of 20 slides at 15 seconds per slide. This will be an opportunity for presenters to get a bigger audience for your key ideas and for the audience to get a wide variety of fast-moving and stimulating talks. Details of presenters within the session will be available in due course.

■ MB-05

Monday, 10:30-12:00 - A003

OR for Development and Developing Countries 2

Stream: OR for Development and Developing Countries
Invited session
Chair: Milagros Baldemor
Chair: Olabode Adewoye

1 - Modelling in Operations Research and its Applications
Olabode Adewoye

One of the main methodologies of Operations Research (OR) is model construction. OR gathers information about a system and tries to formulate models of such system. It is on this formulation that the model is analysed for the purpose of decision making. Modelling, like any other human activity is goal- oriented. However it is an activity subordinated to other activities related to our artificial and natural environment. Despite many importance associated with modelling in OR, there are also some problems ranging from: problem of representation variables/ factors, skills of the modellers, data collection and availability, etc. This paper provides strategies for handling some of the problems mentioned above; schematic classification of models, model development, model design and models for information generation. Reference is made on Policy iteration methods on semi - Markov decision processes.

2 - Gender gap in Managerial Level: A study of civil service in Kathmandu Valley
Sunity Shrestha Hada, Gyan Bahadur Tamang

This paper aims to examine the factors influencing on being in managerial level (decision making level) among civil service officers working at government service in Kathmandu valley. The paper targets at development of gender-specific model predicting the likelihood of being in managerial level.

The paper has adopted objectivist research approach. In total, 254 civil service officers participated in self-administrated survey conducted in Kathmandu valley during the year 2015/2016. The research has performed binomial logistic regression analysis to examine the effects of human capital components, networking behaviors, masculine hegemonic culture and family responsibilities on predicting the likelihood of being in managerial level.

Human capital components: occupational tenure and foreign training; and networking behavior: being visible are significant variables that influence on predicting the likelihood of being in managerial level. However, occupational tenure did not predict the likelihood of being in managerial level for women. None of family responsibilities and masculine hegemonic culture were found to influence on being in managerial level.

The paper is an additional empirical evidence on career development literature with respect to objective career success from gender perspective. In addition, literature on gender balance at workplace has also been added with additional evidence.

3 - Parameter Performances of Patients flow in an Intensive Care Unit of 44 Nigerian Army Reference Hospital, Kaduna: Recursive Queue Model Approach
Michael Oladejo, Kehinde Adenegan, Philip Odion, Ayoyinka Akolawole Akanbi

Prolong waiting on a queue has posed great threat to the health sector which led to loss of lives especially in the accidents and emergency cases, but reduction in this waiting time usually requires planning and extra investments. To enhance the level of tolerance, this research formulated a recursive queue model that can be used to minimise the number of death by varying the number of death in the hospital when the system is invariant of time (steady state). The arrival pattern follows a Poisson distribution while the service rate is exponentially distributed. Oladejo-Agashua modified model was used to estimate the existing and proposed optimal model structure of the hospital. Algebraic expression also was used to compute the recursive model when the number of death varies according to hospital tolerance policy. The recursive model will enable the hospital administrator to choose the policy permissible for varying number of death base on their tolerance limit.

■ MB-06

Monday, 10:30-12:00 - A004

OR for Energy Systems Integration

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: *Valentin Bertsch*
Chair: *Mel Devine*

1 - Exploring the potential of wastewater treatment facilities to contribute to power system flexibility: an integrated energy systems approach
Dana Kirchem, Muireann Lynch, Eoin Casey, Juha Kiviluoma, Valentin Bertsch

Wastewater treatment is an electricity-intensive process with technical potential for load flexibility. This makes wastewater treatment plants (WWTPs) good candidates for participation in demand response (DR) programs. The potential of WWTPs to provide DR has been investigated in several case studies. However, modelling approaches from the WWTP perspective generally neglect the interaction with the power system, while many power system models include DR only as a generic resource. We use a data-driven energy systems model called Backbone to model an Activated Sludge wastewater treatment process within a detailed power systems model for the first time. Backbone minimises total system costs as a mixed-integer linear optimization program (MILP). As a case study, we model the Irish power system, including pumped hydro storage and uncertainties that arise from wind power generation. Wastewater treatment is modelled based on the well-established Activated Sludge Model 1 (ASM1). Non-linear relationships between process variables are linearised in order to fit the mixed-integer linear optimisation approach. Benchmark data is combined with regional rain fall patterns and data on agglomeration sizes to create hourly wastewater inflows. This novel integrated approach combines the process knowledge from WWTP simulation models with power systems optimisation to yield new insights about the technical and economic DR potential from WWTPs.

2 - Representing individual heating in energy systems models
Ida Græsted Jensen, Marie Münster, Rasmus Bramstoft

Individual heating is an important sector often overlooked by energy systems models but with an increasing amount of sustainable energy options, it becomes important to include in these models. These options includes, e.g., heat pumps, district heating network expansion, energy savings, and usage of renewable gasses. Renewable gasses are expected to have an important place in the fossil fuel free energy systems of the future. To evaluate where the renewable gas should be used, it is even more important to include the most relevant sectors in the energy systems models used for evaluating the future use of renewable gasses. In the energy systems model Balmorel, the electricity and district heating systems are included in the model but the individual heating from other sources than electricity is excluded. We present a simplified representation of individual heating in energy systems model taking into account the possibility of district heating network expansions, lifetime of existing individual heating technologies, and hybrid heating systems combining, e.g., a gas boiler and an electric heat pump. Thereby we will be able to find the optimal combination of district heating expansions, deployment of new technologies, and energy savings.

3 - Model coupling for photovoltaic integration through electric vehicle in Germany in 2030
Katrin Seddig, Patrick Jochem, Wolf Fichtner

Electric vehicles (EV) represent one of the most promising technologies towards sustainable and green transport systems. The integration of local power generation by photovoltaic (PV) through charging coordination of EVs could enhance their potential. Apart from that, for the forecast of EV penetration until 2030 exist still different forecasts path. Hence, a detailed consideration of the EV charging loads and the PV generation seems to be necessary. This paper includes a model coupling of an optimization and a system dynamic model. The latter one, TE3, forecasts the penetration of EV for Germany in 2030. This generated data is used to addresses the impacts of the corresponding charging loads through a cost-minimizing and a maximum-utilization of generated PV through an optimization model. The charging loads of the EVs are specified through probability density functions of the three different charging locations at home, work and leisure to show the existing load flexibilities for Germany in 2030. Through an embedded simulation into the optimization model different scenarios will be evaluated. Numerical results are presented and its possible policy implications are derived.

4 - Modeling Multi Energy Carrier Systems in the European Context
Felix Boeing

Achieving the climate protection goals of Paris is a central task for today's scientists. While electricity market modeling has been used for a very long time to answer questions on reducing emissions in the electricity sector, system boundaries have steadily expanded in the context of decarbonization. The energy carriers district heating, hydrogen, methane, synthetic fuels or biomass can no longer be neglected in the sense of a holistic modelling of energy transition. The various technologies for the conversion or generation of these energy carriers need to be considered in a linear optimization model. The constraints, input data and results of scenario analyses in the European context are to be analyzed. In addition to the balance per energy carrier, special cases such as the addition of hydrogen to the natural gas grid or multi-output processes are elaborated. Modelling approaches for mapping sector coupling and optimization results from sensitivity analyses are researched. In this context, both input data and modelling approaches are to be critically evaluated. Not only the determination of an optimization problem for multi-energy carrier systems is relevant, but also the allocation of emissions to energy sources. It is described how to deal with multi-output processes or emission reductions, such as CO2 capture from air or biomass. The work is intended to lead to a better understanding of the systemic repercussions of sector coupling technologies and their flexibility.

■ MB-07

Monday, 10:30-12:00 - A007

Queue and Related Topics

Stream: Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: *Mohan Chaudhry*

1 - Perturbation analysis of two queues with random time-limited polling
Mayank Saxena, Onno Boxma, Stella Kapodistria, Rudesindo Núñez Queija

In this talk, we consider a polling model with a variation of the randomly timed gated service discipline. In this variation, the server does not switch to the other queue when the queue currently receiving service becomes empty, but the server only switches when an exponential timer expires. There are two advantages in this service discipline variation. It enables to: i) keep the frequency of switching at a predetermined level (thus controlling the total cost, if there is a switching cost), ii) balance the time that the server spends in each queue (contrary to exhaustive or gated service disciplines, this discipline does not depend on the number of customers present in the various queues). The polling model at hand violates the branching property, and as such no direct analytic derivation of the joint queue length distribution is known. To this end, we explore the use of (parametric) perturbation. There is a rich choice in which parameters to perturb. In this talk, we illustrate how this choice effects the nature and the complexity of the underlying solution. Furthermore, for a specific choice, we demonstrate how to derive the initial solution (required for the perturbation analysis) and how to built and solve the recursions, leading to the computation of the joint queue length distribution.

2 - Analytically explicit results for the distribution of number of customers served during a busy period for the discrete-time queue - Geom/G/1
Mohan Chaudhry

In this paper, we give analytically explicit results for the distribution of the number of customers served during a busy period for the discrete-time queueing model Geom/G/1 with late-arrival system and delayed-access (LAS-DA) as well as an early-arrival system (EAS). We derive explicit analytic expressions for these distributions using the Lagrange Inversion Theorem applied to probability generating functions. The results are verified numerically by checking the means and variances derived from the analytic results against those obtained from the generating functions. Several cases of the service-time distribution such as Geom, Negative Binomial, Binomial, Deterministic uniform and arbitrary are discussed for both the systems LAS-DA and EAS.

3 - Asymptotic methods in performance modeling of finite-source retrial queues with collisions and their applications in smart city networks
Janos Sztrik

The goal of the present paper is to analyze the steady-state distribution of the waiting time in a finite source M/G/1 retrial queuing system where collisions may happen and the server is unreliable. The failure rates depend on whether the server is bus or idle. An asymptotic method is used when N tends to infinity, the arrival intensity from the sources, intensity of repeated calls tend to zero while service intensity, breakdown intensity, recovery intensity are fixed. It is proved that the steady-state probability distribution of the number of transitions/retrials of a customer into the orbit is geometric, and the waiting time of a customer is generalized exponentially distributed. The average total service time of a custom is also determined. Our new contribution to this topic is the inclusion of breakdown and recovery of the server. Prelimit distributions obtained by means of stochastic simulation are compared to the asymptotic ones. Several examples are treated and figures show the accuracy and the area of applicability of the proposed asymptotic method. As a possibly application of the model smart city networks are considered.

The work/publication of J. Sztrik is supported by the EFOP-3.6.1-16-2016-00022 project. The project is co-financed by the European Union and the European Social Fund.

4 - Meta-model for Estimating Production Rate in an Assembly Manufacturing System Considering Mixed-model
Dug Hee Moon, Young Hoon Lee, Dongok Kim, Yang Woo Shin

The estimation of production rate (or throughput) is the major concern in the phase of manufacturing system design. Two approaches have been used for estimating the performance measures, and they mathematical models using stochastic processes such as queueing network models, and simulation. Although mathematical model is better, it is difficult to develop when the system becomes complex. On the contrary, simulation is easy to apply for the complex system, but simulation has demerits when used for the optimization problem of the system due to the large number of experiments and simulation run time. Therefore, meta-model based on simulation results becomes another alternative. In this study, an approach for developing quadratic meta-model in a complex assembly system which consists of multiple sub-lines with no buffer and finite buffer between the two sub-lines. Body shop in an au-tomotive factory is the one of examples of the system considered. We also consider that two types of cars are produced and the rate of product-mix can be varied. The factors considered for meta-model are product mix, process times, isolated efficiency of unreliable station and the number of buffers between sub-lines in a given layout and transfer strategy. The accuracy of meta-model are within 3% relative to the simulation results. Thus, developed meta-model can be used for the optimization problem.

■ MB-08

Monday, 10:30-12:00 - A008

Modelling approaches to speed-up energy system models: Heuristics and exact methods

Stream: Modelling & Analytics for Energy Economics II
Invited session
Chair: Frieder Borggrefe

1 - Performance analysis of selected conceptual speed-up methods to improve computation time of energy system models
Kai von Krbek, Karl-Kien Cao

Energy system models are used among others to investigate scenarios for future electricity system scenarios for Europe and other regions in the world. A detailed representation of the underlying real world system is required to draw valuable scientific insights. In recent years these models became increasingly complex to depict the more and more decentralized system and to be able to answer todays (and future) research questions. While the amount of input data is increasing, modelers face the difficulty to be able to solve these complex models.

In this paper we discuss different conceptual methods to reduce computation time of energy system models. Six energy system models by German, Swiss and Danish research institutions participated in the model comparison. Focus of this benchmark analysis is to evaluate the trade-off between model accuracy and time to solve the energy model. Different methods to reduce the complexity of the model such as rolling horizon, rolling investment, reduction of time slices and decomposition are implemented in energy system models. The paper compares the quality of the results based on various key indicators such as dispatch, full load hours and prices. Finally it derives general insights and recommendations for best practices for both dispatch and integrated investment models. The paper draws on results of the BEAM-ME project, a three year research project addressing to enhance methods to reduce computation time of energy system models.

2 - Acceleration strategies for speeding up the solution time of the TIMES energy systems model generator - findings from the BEAM-ME project
Evangelos Panos, Aymane Hassan

We present the findings from the application of different acceleration strategies assessed in the BEAM-ME project for speeding up the EUSTEM model. The model represents the electricity system of EU-28 and it is based on the TIMES model generator of the International Energy Agency. The temporal aggregation speeds up EUSTEM, but the solutions overestimate the uptake of variable renewables and underestimate the deployment of flexible capacity (smoothening of the load curves). The spatial aggregation reduces solution times but the solutions overestimate the deployment of renewables and underestimate congestion and flexible capacities needs (aggregation of resources, elimination of transmission constraints). The rolling investment horizon mimics the limited foresight of decision-makers, but depending on the length of the steps it can either produce similar behaviour as the perfect foresight or result in delayed technology deployment and choose options not used in the future. Solving the model in High Performance Computing with the parallel solver PIPS-IPM seems the preferable option. The model is annotated to reveal its block-diagonal matrix structure to the solver. Solver's limitations in the maximum number of linking constraints and variables, and limitations in the minimum number of blocks for good degree of parallelisation, require several annotation strategies to be tested. However, the reduction in solution time is worth the effort needed to achieve a suitable annotation.

3 - Reducing Energy Time Series for Energy System Models via Self-Organizing Maps
Dogan Keles, Hasan Ümitcan Yilmaz, Edouard Fouché, Thomas Dengiz

Modeling the intermittent character of renewable energy sources increases the complexity of energy system models(ESM), because it is essential to consider the weather-dependent electricity production with a sufficient time resolution. Using data with high level of granularity leads to long execution times, ranging from many hours to days. Furthermore, simply reducing the data e.g. via aggregation reduces the quality of the model results. In this study, the objective is to reduce energy time series without losing their key characteristics. This is challenging, because of the high-dimensionality of data. Therefore, we describe a methodology to prepare, process, and reduce the data. The proposed approach uses self-organizing maps(SOM), a specific type of artificial neural networks, for clustering the data. Afterwards representative days from each cluster are selected and these days are weighted with the number of elements in their cluster. Thus, a reduced time structure is created. An exemplary ESM is then executed with the created time structure and the results are compared with the ones from model runs with the complete data. This process is repeated for different clustering algorithms, input data, and ESM configurations. The study shows that the presented approach using SOMs outperforms other approaches, such as typical days and other clustering algorithms, and leads to high reductions in the execution time of ESMs without significantly worsening the quality of the results.

4 - How to speed-up computing time of energy system models: key findings from the BEAM-ME project
Frieder Borggrefe, Olexandr Balyk, Stefanie Buchholz, Hannes Hobbie, Samir Jeddi, Robin Leisen, Evangelos Panos, David Schönheit

This paper provides results from the BEAM-ME project. The project was conducted by an interdisciplinary team of energy modelers, Software developer, experts in high performance computing and operation research. One aim of the project was to develop a novel approach for distributed computing and application of energy system models to high performance computing. Further the project investigated conceptual speed-up methods. In this paper we provide an overview of the main lessons learned from the different approaches. It outlines difficulties that arise for modelers when applying energy system models based on linear programming on large scale distributed machines. Further it offers suggestions for modelers how speed-up of energy system could be reached from a modelling perspective. BEAM-Me project is funded by the German Ministry of Economic Affairs and Energy.

■ MB-09

Monday, 10:30-12:00 - B006

DEA applications in Education

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Giovanna D'Inverno

1 - Managerial Efficiency and Efficiency Differentials in Adult Education: A Conditional and Bias-Corrected Efficiency Analysis
Deni Mazrekaj

This article proposes an advanced conditional efficiency model that estimates efficiency while accounting for sampling noise. In particular, we extend the conditional efficiency model by correcting for bias within conditional draws, using the m out of n bootstrap procedure. With a unique panel dataset, we estimate managerial efficiency (i.e. accounting for nondiscretionary variables) and explain efficiency differentials of adult education programs in Flanders. Our results suggest that the characteristics of learners in a program matter for managerial efficiency, and that teacher characteristics are strongly correlated with efficiency differentials, as more homogeneity in the teacher workforce appears to result in higher program efficiency.

2 - Incorporating quality considerations in DEA-based benchmarking of higher education
Margareta Gardijan Kedžo, Ozana Nadoveza Jelić

It is well known that DEA has been used for estimating and ranking education on different levels (primary, secondary, tertiary) and across different units (schools, universities, countries, ...). However, DEA is a method that generally rewards the greater quantity of the output and the fewer inputs, which raises some question about the results of the DEA-based research of education since the education is a specific area where the quality of the output and the quality of the input matter more than the quantity itself. Despite that fact, many of the previous studies overlooked to incorporate the output quality considerations in their research. Also, the researches should be adjusted for input quality to avoid potential bias towards low input units within DEA. In our research, we investigate the use of data envelopment analysis (DEA) for benchmarking the higher education using multiple criteria and the possibilities to incorporate quality considerations of education by using different DEA models and the quality measures/ corrections of inputs and outputs. Our sample contains 24 EU countries in the period of 2004-2015. Preliminary results indicate that the outcome of the analysis can change significantly when quality concerns are included. A part of the results was published in a paper submitted for the award of the Prof. Dr. Marijan Hanžeković Prize in 2018.

3 - Non-compensatory Efficiency Measures for a balanced comparison of European Higher Education institutions
Thyago Nepomuceno, Ana Paula Costa, Cinzia Daraio

Composite indicators are widely adopted measures in Higher Education to assess, compare and reward faculty and universities based on teaching and research outcomes. A rigorous discussion about the development of meaningful university rankings or league tables based on composite indicators implies the deep investigation on the complementarity and substitutability between some inputs and/or some outputs (e.g. teaching vs. research). Such additive compensation sometimes does not represent properly the preference structure of universities decision makers, leading to cases in which poor quality education, low student retention, and employability are compensated by higher research performance, or otherwise. In this work, we study some of the most adopted methodologies to rank and analyze the efficiency of European Higher Education Institutions (HEIs) and propose alternative non-compensatory approach. The results can be used to aid resource allocation, identify benchmarks and efficient educational practices based on a balanced modeling of the educational and research (academic) production process.

4 - Impact evaluation in a multi-input multi-output setting: Evidence on the effect of additional resources for schools
Giovanna D'Inverno, Mike Smet, Kristof De Witte

This paper proposes an innovative approach to evaluate the causal impact of a policy change in a multi-input multi-output setting. It combines varied insights from the econometric impact evaluation techniques and the efficiency analysis. In particular, the current paper accounts for endogeneity issues by introducing a quasi-experimental setting within a conditional multi-input multi-output efficiency framework and decompose the overall efficiency between 'group-specific' efficiency (i.e., reflecting internal managerial inefficiency) and 'program' efficiency (i.e., explaining the impact of the policy intervention on performance). This framework allows the researcher to interpret the efficiency scores in terms of causality. The practical usefulness of the methodology is demonstrated through an application to secondary schools in Flanders, Belgium. By exploiting an exogenous threshold, the paper examines whether additional resources for disadvantaged students impact the efficiency of schools. The empirical results indicate that additional resources do not causally influence efficiency around the threshold.

■ MB-10

Monday, 10:30-12:00 - H0.12

Recent Advances in Discrete Robust Optimization

Stream: Robust Optimization
Invited session
Chair: Jannis Kurtz

1 - Two-stage Robust Optimization for Non-Linear Combinatorial Problems
Jannis Kurtz, Nicolas Kämmerling

In this talk we study robust two-stage counterparts of non-linear combinatorial optimization problems. Our main approach is to linearize the underlying non-linear problem and afterwards adapt existing results for linear problems to our setting. We present a Branch & Bound procedure which branches over the first-stage decisions. A lower bound in each node of the Branch & Bound tree is calculated by an oracle-based algorithm which iteratively solves the deterministic non-linear problem. We apply our procedure to the Uncapacitated Single-Allocation Hub Location Problem with uncertain demands which can be modeled by a quadratic binary formulation.

2 - The Bulk-Robust Disjoint Paths Problem
Felix Hommelsheim, David Adjiashvili, Moritz Mühlenthaler, Oliver Schaudt

We consider the following variant of the bulk-robust disjoint paths problem. We are given a graph and a list of scenarios, each consisting of edges of size at most l that are deleted if the scenario materializes. The task is to select a minimum-cost subset of edges of the graph that contains k disjoint s-t paths, no matter which scenario materializes. Based on the work on the bulk-robust shortest path problem by Adjiashvili, Stiller and Zenklusen (2015) we present a polynomial-time logarithmic-factor approximation algorithm for the bulk-robust disjoint paths problem if k and l are constant. We show that in contrast, the task of making given k disjoint paths robust against the failure of single edges, admits a polynomial-time algorithm.

3 - How to Secure Matchings Against Edge Failures
Moritz Mühlenthaler, Felix Hommelsheim, Oliver Schaudt

Suppose we are given a bipartite graph that admits a perfect matching and an adversary may delete any edge from the graph with the intention of destroying all perfect matchings. We consider the task of adding a minimum cost edge-set to the graph, such that the adversary never wins. We show that this task is equivalent to covering a digraph with non-trivial strongly connected components at minimal cost. We provide efficient exact and approximation algorithms for this task. In particular, for the unit-cost problem, we give a (log n)-factor approximation algorithm and a polynomial-time algorithm for chordal-bipartite graphs. Furthermore, we give a fixed parameter algorithm for the problem parameterized by the treewidth of the input graph. For general non-negative weights we prove a dichotomy theorem characterizing minor-closed graph classes which allow for a polynomial-time algorithm. To obtain our results, we exploit a close relation to the classical Strong Connectivity Augmentation problem as well as directed Steiner problems.

4 - Bootstrap Approach to Quantifying Uncertainty of Index Tracking and Enhanced Indexation
Hakim Mezali

Index tracking and enhanced indexation have become popular methods of passively managing mutual funds that attempt to mirror and outperform the index respectively. While a great deal of attention has been directed towards formulating models, very little effort has been focused on quantifying the level of uncertainty associated with portfolio selected by these models. In light of index tracking and enhanced indexation, the quantification of uncertainty is of paramount importance as this provides investors indication of a degree of risk that can be expected as a result of holding the selected portfolio over the holding period. In this paper, a bootstrap approach is employed to quantify the uncertainty of portfolio selected from regression models.

■ MB-11

Monday, 10:30-12:00 - H1.12

Vector and Set-Valued Optimization II

Stream: Vector and Set-Valued Optimization
Invited session
Chair: *César Gutiérrez*

1 - Vector-based robust efficiency in uncertain optimization
Marcin Studniarski

In our paper "Necessary and sufficient conditions for robust Q-minimal solutions in uncertain vector optimization" (joint work with A. Michalak and A. Stasiak; partially presented at the previous EURO 2018 Conference) we have introduced a new definition of a vector-based robust Q-minimal solution of an uncertain vector optimization problem, proved a characterization of this kind of solution in terms of radial directional derivatives, and examined some relationships between this new definition and several existing ones. The aim of this talk is to find out which results of the previous paper remain in force if the open cone Q is replaced by a closed convex cone K with nonempty interior.

2 - Density results and geometry of cones
Fernando García Castaño, Miguel Angel Melguizo Padial

We consider two theorems of Arrow, Barankin and Blackwell's type, one due to M. Petschke and another to X. H. Gong. Both results concern the approximation of the Pareto efficient points of compact convex subsets in ordered normed spaces by points that are maximizers of some strictly positive functional on this set. Later, A. Daniilidis analysed the geometry of the corresponding order cone and proved that in ordered Banach spaces the former theorems become equivalent. However, such an equivalence for noncomplete normed spaces was stated as an open problem by Gong. In this talk we will state some results regarding the geometry of the order cone which provide an answer to such a question.

3 - A Set-Valued Lagrange Theorem based on Processes for Convex Set-Valued Programming
Miguel Angel Melguizo Padial, Fernando García Castaño

In this talk we present a new set-valued Lagrange theorem for convex set-valued optimization programs with set-valued constraints. The role traditionally played by linear continuous operators is now carried out by processes, their set-valued analogues. We introduce the novel concept of Lagrange process as a natural extension of the classical concept of Lagrange multiplier. This new set-valued multiplier seems to be particularly appropriate if it has a bounded base or for some proper efficient points.

4 - Characterizations of weakly efficient solutions of vector optimization problems
César Gutiérrez

This talk focuses on the so-called weakly efficient solutions of vector optimization problems with set-valued mappings. Such solutions are defined via a free disposal domination set with respect to the ordering cone of the problem. By considering suitable generalized convexity hypotheses, linear scalarization results and Lagrangian multiplier rules are provided. These optimality conditions encompass and improve several recent results of the literature, as they work in problems whose ordering cone has nonempty quasi interior and weaker assumptions are required

■ MB-12

Monday, 10:30-12:00 - H1.51

Topics in Combinatorial Optimization I

Stream: Combinatorial Optimization I
Invited session
Chair: *Michele Monaci*

1 - Optimal vehicle routing with autonomous devices for last-mile delivery
Marcos de Melo da Silva, Laurent Alfandari, Ivana Ljubic

In this work we study the Routing-Scheduling Problem (RSP), a routing problem which uses autonomous devices for last-mile delivery. The RSP aims at finding an optimal route for a vehicle carrying customer parcels from a central depot to selected facilities, from where autonomous devices like drones or robots are launched to perform last-mile deliveries. The objective is to minimize a lateness indicator, given customer delivery due dates. In addition, three scheduling variants are considered: min-max, min-sum and min-num, referring to minimizing the maximum tardiness, the total tardiness, and the number of late deliveries, respectively. After providing a formal definition of the problem for such tardiness objective functions, we investigate their complexity and devise a (generic) Mixed Integer Programming (MIP) multi-commodity network flow formulation. To deal with instances of realistic size, we propose a Benders Decomposition approach that can be implemented in a generic way for all three problem variants. Furthermore, we show how Benders cuts can be generated without resorting to linear programming to solve the Benders subproblems, and use a combinatorial approach instead. Three variants of the proposed Benders decomposition are implemented and their performance are analyzed using adapted instances from the literature. Numerical results show that the Benders approach with the tailored combinatorial algorithm for generating the Benders cuts outperforms the other approaches.

2 - Lower and upper bounds for the Non-Linear Generalized Assignment Problem
Michele Monaci, Claudia D'Ambrosio, Silvano Martello

Given a set of n items, each with positive profit and weight, and a container (knapsack) with a given capacity, the Knapsack Problem (KP) requires to select a subset of items so that the total weight of the selected items does not exceed the capacity and the total profit of the selected items is a maximum. One of the most studied generalizations of the KP is the Generalized Assignment Problem (GAP). In this problem, there are m heterogeneous knapsacks available for packing the items, and the profit and weight associated with the packing of a certain item j into a certain knapsack i depend on both i and j. While the KP is weakly NP-hard and can be solved efficiently in practice, the GAP is strongly NP-hard and turns out to be extremely challenging from a computational viewpoint. We consider a version of the GAP in which the items can be fractionated among knapsacks, and profits and weights are described by general non-linear functions. The resulting

Non-Linear Generalized Assignment Problem (NLGAP) is a continuous optimization problem in which nonlinearities appear both in the objective function and in (some of) the constraints. We present lower and upper bound procedures based on (Integer) Linear Programming, and compare their computational performances with those obtained applying state-of-the-art non-linear solvers on a natural formulation of the problem.

3 - Genetic Algorithm to solve Solid Assignment Problem
Mohamed Mehbali, Abdellah Salhi, Dhia Kadhem

In this paper, we examine the 3-dimensional assignment problem also called Solid Assignment Problem (SAP), which is an extended version of the well-known classic 2-dimensional assignment problem. SAP consists of allocating n jobs to n machines in n factories, such that exactly one job is assigned to one machine in one factory, the objective being to minimise the total cost of such allocation. SAP is a combinatorial optimisation problem with a wide range of applications, as it has been the object of numerous research endeavours. The problem is known to be NP-hard; due to its inextricable nature, the largest instance of SAP solved to date with an exact method is only of size n = 26. A heuristic based on the Genetic Algorithm (GA) is designed to approximately solve SAP, to obtain an initial feasible solution we propose two methods namely a random permuted number function and the Hungarian method. Experimental results obtained with an implementation of our approach are reported. These results are compared with those obtained by Branch-and-Bound (B&B) on medium to large SAP instances and show that our approach returns similar or better solutions in a competitive time.

Key words: Solid assignment problem, genetic algorithm, branch-and-bound method and Hungarian method.

■ MB-13

Monday, 10:30-12:00 - H2.12

Discrete and Global Optimization II

Stream: Discrete and Global Optimization
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Jan van Vuuren*
Chair: *Peter Gritzmann*

1 - A quantitative model for describing road accident risk along a road network
Shane van Heerden, Jan van Vuuren, Sara S Grobbelaar

According to the World Health Organisation, road accidents account for approximately 1.25 million deaths annually, making them the eighth leading cause of death worldwide. With the enormous losses to society resulting from road accidents, their prevention and severity reduction have been an active area of research focus for many decades. One such research approach focusses on developing descriptive models for describing the road safety situation based on historically recorded road accident and exposure data.

In this presentation, a descriptive modelling approach is proposed which attempts to quantitatively describe the risk experienced along a road network, where risk, in this context, is modelled as a bivariate function of the likelihood and consequence of being involved in a road accident. The prospect is that such a formulation may serve as a novel routing objective which attempts to minimise the total risk of experiencing a road accident when travelling on a given road network. The proposed modelling approach is applied to a real-world case study so as to demonstrate its intended functionality in a real-life setting.

2 - A mathematical description of the relationship between power possessed and gain expected
Ryan Reed, Jan van Vuuren

The mysteries surrounding the dynamics that govern the mechanisms of human interaction have often dominated the pursuit of scientific enquiry throughout history. The fact that this pursuit remains indefinite suggests that either its methods are failing, or that the phenomenon being studied is intractably complex. In view of the delineated history of this pursuit, the former reason for its continuation is rejected. Accordingly, the work covered in this presentation represents an attempt to further the general understanding of competitive human interaction by employing the unique utility of mathematical modelling, first to describe and then to explore the dynamics that govern the interaction of competing entities during the prototypical process that surrounds the formulation of real-world problems. More specifically, the interaction of competing entities is investigated through the lens of the relationship between the notions of power possessed and gain expected, in the context of real-world systems that exhibit the following property: The entities contained therein are forced to coexist despite pursuing conflicting objectives.

3 - A hyperheuristic approach towards the training of artificial neural networks
Stephan Nel, Jan van Vuuren

Conventionally, gradient based approaches are employed to train artificial neural networks. A limitation is, however, imposed on the level of abstraction at which optimisation can transpire. A metaheuristic optimisation approach, on the other hand, circumvents this limitation, allowing the network weights, structure, and activation functions to be optimised concurrently. A challenge to all optimisation approaches, however, relates to the decision of which algorithm to employ for this purpose. Fortunately, the relatively new and promising field of hyperheuristics provides a means to circumvent this challenge — a hyperheuristic is essentially a heuristic that chooses heuristics. In this study, a multi-algorithm, genetically adaptive multi-objective (AMALGAM) hyperheuristic approach is adopted towards the concurrent training of feedforward neural networks in respect of their weights, structure, and activation functions — an unaddressed matter in the literature. To this end, a bi-objective hyperheuristic training algorithm is employed, in which the main objective represents a novel performance measure that incorporates both mean absolute error and the well-known F1 score, while a secondary so-called helper objective helps guide the search process. The proposed hyperheuristic comprises three evolutionary algorithms together with a powerful variant of gradient descent. The efficacy of the proposed solution methodology is evaluated in respect of a test suite of diverse data

4 - On Tomographic Particle Tracking
Andreas Alpers

The task in tomographic particle tracking is to reconstruct the paths of a set of points over time, where, at each of a finite set of moments in time the current positions of the points in space is only accessible through a small number of tomographic measurements (i.e., through their projections counted with multiplicity along some lines).

In this talk we focus on combinatorial models. In these models the positions of the particles in the next time step are assumed to be known approximatively in the sense that the candidate positions are confined to certain windows, which are finite subsets of positions.

It turns out that the computational complexity of the reconstruction task, which can always be formulated as a discrete optimization problem, depends strongly on the type of windows employed in the model.

This is joint work with Peter Gritzmann (TU Muenchen).

■ MB-15

Monday, 10:30-12:00 - H2.32

Optimization and Equilibrium Problems on Riemannian Manifolds 2

Stream: Mathematical Programming
Invited session
Chair: *Alexandru Kristaly*

1 - Divergences and related optimization problems on symmetric cones
Sangho Kum

The motivation of this work is basically concerned with optimization methods for the L2-Wasserstein least squares problem of Gaussian measures (alternatively the n-coupling problem). Based on its equivalent form on the convex cone of positive definite matrices and the strict convexity of the variance function, an implementable (accelerated) gradient method for finding the unique minimizer is already presented by Kum and Yun. On the other hand, the notion of fidelity plays an important role in quantum information theory and quantum computation. It has a deep connections with quantum entanglement, quantum chaos, and quantum transitions. It also occurs in the context of the Wasserstein distance (or the Bures distance). Recently, a parametrized version of fidelity has been studied. It is called the sandwiched quasi-relative entropy. In this talk, a divergence concerned with the sandwiched entropy and its related optimization problems are discussed in the general symmetric cone setting. In particular, an explicit formula for the the L2-Wasserstein barycenter is provided on symmetric cones.

2 - Multipolar Hardy inequalities on Riemannian manifolds
Csaba Farkas, Francesca Faraci, Alexandru Kristaly

In this talk, we prove multipolar Hardy inequalities on complete Riemannian manifolds, providing various curved counterparts of some Euclidean multipolar inequalities due to Cazacu and Zuazua [Improved multipolar Hardy inequalities, 2013]. We will notice also that our inequalities deeply depend on the curvature, providing (quantitative) information about the deflection from the flat case. By using these inequalities together with variational methods and group-theoretical arguments, we also establish non-existence, existence and multiplicity results for certain Schrödinger-type problems involving the Laplace-Beltrami operator and bipolar potentials on Cartan-Hadamard manifolds and on the open upper hemisphere, respectively.

3 - Stochastic linear complementarity problems on extended second order cones
Lianghai Xiao, Sándor Zoltán Németh

This paper is based on our research about the linear complementarity problem on extended second order cones. We reformulate the linear complementarity problem on extended second order cones into a stochastic version. Since it involves uncertainty, it becomes impractical to find a solution for the stochastic linear complementarity problem on an extended second order cone. The existence of the random vector will generate too many complementarity constraints. Hence, it is plausible to use probability models to make the solution of this problem attainable. In addition, concession has been made between the solvability of the problem and the complementarity constraints. We use CVaR method to measure the loss of complementarity and construct a new model based on it. In addition, algorithms are given for solving the stochastic linear complementarity problem on extended second order cones.

4 - Equality in Riemannian geometric inequalities via optimal mass transportation
Alexandru Kristaly, Zoltán Balogh

By using optimal mass transportation and a quantitative Hölder inequality we provide estimates for the Borell-Brascamp-Lieb deficit on complete Riemannian manifolds. Accordingly, equality cases in Borell-Brascamp-Lieb inequalities (including Brunn-Minkowski and Prékopa-Leindler inequalities) are characterized in terms of the optimal transport map between suitable marginal probability measures. These results provide several qualitative applications both in the flat and non-flat frameworks. In particular, a precise characterization is provided for the equality in the Lott-Sturm-Villani-type distorted Brunn-Minkowski inequality on Riemannian manifolds with Ricci curvature bounded from below. The talk is based on the paper by Z.M. Balogh and A. Kristály, Equality in Borell-Brascamp-Lieb inequalities on curved spaces. Adv. Math. 339 (2018), 453-494.

■ MB-16

Monday, 10:30-12:00 - Theatre A

Matheuristics for Combinatorial Optimization Problems I

Stream: Combinatorial Optimization II
Invited session
Chair: Claudia Archetti

1 - A hybrid model based matheuristic for an arc routing application
Leonor S.Pinto, João Janela, Cândida Mourão

This work focuses on a household waste collection system in the Portuguese municipality of Seixal modelled by a Mixed Capacitated Arc Routing Problem (MCARP). The solving methodology uses a GIS (Geographic Information System), available at the municipality, for the input/output, and a two-phase heuristic developed for this case study. During the first phase, called sectoring, the links demanding for service (tasks) are assigned to sectors, one per vehicle, while in the second phase, named routing, the vehicle trips are designed. Different stopping criteria in the first phase demand for different methods in the second phase. In a first approach all tasks are assigned to only one sector and thus, in the second phase, each trip is generated through an adapted flow model. In a second approach, some tasks are not assigned during the first phase, and so, the remaining tasks are assigned to sectors within the trips design through a matheuristic involving a new hybrid flow model. The quality of the generated solutions is accessed through the total time, and through some attractiveness measures that aim to evaluate their fitness to the real case study, a crucial aspect for routes that need to be accepted by practitioners. A new attractiveness measure, named as Weighted Hull Overlap (WHO), is also proposed. This measure is able to mix the overlapping of routes with the placement of tasks relatively to their ideal boundaries. Computational results on Seixal instances will be reported.

2 - Kernel search for the inventory routing problem
M. Grazia Speranza

The Kernel Search (KS) is a general and simple heuristic framework for the solution of Mixed Integer Linear Programming (MILP) problems. The basic idea of the KS is to solve a sequence of MILP subproblems, each restricted to a subset of variables. The KS has been applied to a variety of specific MILP problems and to a generic MILP problem. When the continuous relaxation of the MILP problem is meaningful, the relaxation is used to identify the initial kernel, that is a set of variables that contains most of the variables that will take nonzero value in the optimal solution of the original MILP. The remaining variables are organized in so called buckets. Each MILP sub-problem is restricted to the current kernel, that is updated at each iteration, and a bucket. It is well known that the continuous relaxation of the MILP formulation for vehicle routing problems (VRPs) is not meaningful. In this talk we present the first KS heuristic applied to a VRP, namely the inventory routing problem (IRP). The heuristic builds the initial kernel and the buckets using the output of a tabu search heuristic. Computational experiments on benchmark instances show that the KS beats previous heuristics for the solution of the IRP.

3 - Modelling and solving a truck scheduling and transhipment problem in a cross-docking terminal
Marcello Sammarra, M. Flavia Monaco

In this talk, we address a truck scheduling problem in a cross-docking terminal, where products arriving by inbound trucks, are arranged with respect to retailers' requirements and directly loaded into the outbound trucks, without being stored inside the terminal. We assume that two docking gates are available, one for the unloading and the other for loading operations, and that the amount of products to be transferred from the inbound to the outbound trucks are known. The objective is to minimize the overall completion time of the operations (makespan). For this basic problem, we propose a new Mixed Integer Linear Programming formulation and a Lagrangian relaxation approach. We show that the Lagrangian relaxed problem decomposes in three structured combinatorial sub-problems, concerning, respectively, the scheduling of trucks at the inbound and outbound gates, and the transhipment flow among the trucks. We propose effective solution algorithms for all the subproblems. These algorithms are enclosed within a multiplier adjustment scheme, equipped with a repairing heuristic aimed at computing feasible solutions for the original problem, starting from the solutions of the relaxed problem. Therefore, the resulting procedure is able to compute both lower bounds of increasing value and many feasible solutions, among which to choose the best one. Finally, we discuss some preliminary numerical results.

■ MB-17

Monday, 10:30-12:00 - A005

Stochastic Models and Queueing: Theory and Applications

Stream: Stochastic Models and Queueing
Invited session
Chair: *Rosa Elvira Lillo Rodríguez*

1 - Staffing in Multi-Stage Call Centers with Overflow
Marc-Philip Piehl, Michael Manitz

Ensuring customer satisfaction is one of the main objects of a call center. We focus on the question how many agents are necessary to hold a service-level threshold and to reduce the expected waiting time. We consider a multi-stage call center which consists of a front office and a back office, impatient customers, and an overflow mechanism. Based on performance evaluation of such a system via a continuous-time Markov chain, an optimal configuration of agents is found by full enumeration. As an alternative we focus on structural insights, e.g. convexity conditions for designing gradient-based approaches for optimization, for reducing computation times.

2 - Improving warehouse responsiveness by job priority management
Thai Young Kim

Warehouses employ order cut-off times to ensure sufficient time for fulfilment. To satisfy increasing consumer's expectations for higher order responsiveness, warehouses competitively postpone these cut-off times upholding the same pick-up time. This paper, therefore, aims to schedule jobs more efficiently to meet compressed response times. Secondly, this paper provides a data-driven decision-making methodology to guarantee the right implementation by the practitioners. Priority-based job scheduling using flow-shop models has been used mainly for manufacturing systems but can be ingeniously applied for warehouse job scheduling to accommodate tighter cut-off times. To assist warehouse managers in decision making for the practical value of these models, this study presents a computer simulation approach to decide which priority rule performs best under which circumstances. The application of stochastic simulation models for uncertain real-life operational environments contributes to the previous literature on deterministic models for theoretical environments. The performance of each rule is evaluated in terms of a joint cost criterion that integrates the objectives of low earliness, low tardiness,low labour idleness, and low work-in-process stocks. The simulation outcomes provide several findings about the strategic views for improving responsiveness. This study closes the existent gap regarding data-driven decision making methodology for practitioners of supply chains.

3 - A real options approach for joint overhaul and replacement strategies with mean reverting prices
Maximiliano Cubillos

Due to its significant impact on economic performance, an effective equipment overhaul and replacement strategy is a key aspect of physical asset management in capital intensive industries, such as the mining industry. Classical approaches suggest periodic interventions based on the physical condition of the equipment, considering factors such as availability and operational costs. These fixed models generally ignore two important aspects: first, the flexibility of the decision to overhaul or replace, which may be re-evaluated within a given period, and second, the uncertainty around economic factors that may affect future maintenance decisions, such as the product price. This work improves on classical models by considering the effect of integrated price uncertainty in the definition of joint overhaul and replacement strategy, using a real options approach and a mean reversion binomial model to represent the uncertainty in price. More specifically, we develop a real options model and use a stochastic optimization algorithm to determine an optimal intervention policy that maximizes expected profits. Results show that the option-based decision model economically outperforms the classical periodic strategy approach from with net present value increments ranging from 36.8 to 8.6%, according to the number of periods in the maintenance cycle, offering evidence that a new approach to equipment overhaul and replacement strategy is needed.

4 - A bidimensional Markovian Arrival Process for modelling failures in trains.
Rosa Elvira Lillo Rodríguez

Based on failures data in a two-dimensional context, this paper presents an extension to the two-dimensional case of the Markovian Arrival Process (MAP). The new process maintains the marginal properties of a MAP but also allows dependence between the two inter-events sequences. The generalization is based on the use of the Marshall-Olkin exponential distribution. Using the Bayesian algorithm ABC, we show an estimation method that presents very good results for simulated data and for the real problem based on failures of a public transport company.

■ MB-18

Monday, 10:30-12:00 - C112

Ensemble and Classifier Selection Algorithms and Applications

Stream: Multiple Classifier Systems and Their Applications
Invited session
Chair: *Sureyya Ozogur-Akyuz*
Chair: *Duygu Ucuncu*

1 - Measurement of Spatial Quality in Public and Public Relations by Weighted Quality Measures: Case Study in Istanbul
Melisa Caliskan, Ebru Erdönmez Dincer, Sureyya Ozogur-Akyuz

Public spaces are one of the main areas of urban life. The main feature of these areas is the areas that urbanize the people of the city. In this context, public spaces are among the most important areas in which urban citizens share and share their cultural backgrounds with all the users, and at the same time they learn the definition of the city and the formation of the city's original image.In this study, it is tried to reveal the relationship between public space and social structure by examining how public spaces are shaped and how they lead their lives to Eminönü-Beyazıt region.In order to examine the spatial quality of public spaces subject to study, Beyazıt square and its surroundings were chosen as one of the historical, cultural and commercial centers of Istanbul.In the study, it is aimed to analyze the spatial quality within the region to provide a report for this area for a better service by using statistical learning approaches. We used factor analysis to understand the important features of the quality assessment and employed the regression analysis to analyze those features for further forecasting.

2 - Ensemble Feature Selection for Sentiment and Semantic Analysis
Ceylan Demir, Sureyya Ozogur-Akyuz, Izzet Goksel

Text mining, also mentioned as text data mining, is the operation of deriving high-quality and useful information from text data. In other words, text mining aims to obtain structured data through text by using feature extraction, classification of texts, sentimental analysis, text summarization. In this study, a novel algorithm is developed for text mining which uses ensemble of feature selection methods and then selects the best feature selection methods based on an optimization framework developed in our previous study for ensemble classification. It aggregates the results of the best feature selection methods by simple voting strategy. We tested our ensemble feature selection algorithm on text mining data sets from Kaggle database and compared the performance measures with the benchmark ensemble selection methods in the literature.

3 - Non-Asymptotic Uncertainty Bounds for Kernel Estimates
Balázs Csáji, Ambrus Tamás, Krisztián Kis

Kernel methods are widely used in several fields, including machine learning, system identification and statistics, typically for classification, regression and density estimation problems. These methods have strong connections to convex optimization as the kernelization of known algorithms is often done through the Wolfe dual of their associated (primal) convex programs. The obtained solutions are usually uncertain, since they depend on randomly sampled observations (constraints). A natural question which arises is that how much can we trust these kernel estimates? Bounding the uncertainty of the solutions is fundamental, for example, for risk management and robust optimization. In this talk, we present a general data-driven framework to build distribution-free confidence regions for kernel estimates with strong non-asymptotic guarantees. Our construction builds on recent developments in finite-sample system identification and it is based on rank tests related to perturbed datasets. We argue that we can rigorously bound the uncertainty of several kernel-based regression and classification methods, assuming we know some mild regularity about the underlying probability distributions, for example, the measurement noises are either symmetric about zero or exchangeable. The approach is demonstrated on arch-typical kernel methods, such as support vector classification and regression, kernel ridge regression and kernelized LASSO (least absolute shrinkage and selection operator).

4 - Data Driven Inventory Control Based on Stochastic Optimization Theory
Ruud Teunter

Traditional inventory models assume that the demand process is given, whereas 'only' historic data is available in practice. In this presentation, I use results from stochastic optimization to develop data driven approaches that base inventory decisions directly on the historical observations of demand and related variables, instead of specifying and forecasting demand and then applying traditional inventory models. I do so for the a single-item newsvendor model with a service level restriction, but these methods can be extended to other inventory models. I propose and compare several methods, based on different results from the field of stochastic optimization. More generally, I also discuss the opportunities and pitfalls of such data mining approaches to inventory control.

■ MB-19
Monday, 10:30-12:00 - C115

Knowledge Work Analytics

Stream: Knowledge and Knowledge Analytics
Invited session
Chair: A. D. Amar

1 - Challenges to Knowledge Operationalization. Example of Chemical Engineering Knowledge within Metal Companies
Rebecca Cason, Vitaliy Smirnov, Kevin Burt

Many metal companies are hit with the wave of retirements among the metallurgists and face the problem to retain the chemical engineering knowledge of their metallurgical processes to ensure stable operations. Typical approach for the metal companies to tackle this problem is to implement the explicit & implicit knowledge management. However, such approach deals with the consequences of the problem and not with its root cause. Our experience of working with metal companies shows that the root cause is a lack of clarity about what chemical engineering knowledge actually is in the operational context (chemical process design, chemical process control, chemical process performance analysis, chemical process optimization, chemical process quality assurance) and, subsequently, its poor operationalization (policies, procedures, standards, guidelines, instructions). Thus, if the metal companies are unclear about the taxonomy of the chemical engineering knowledge, they struggle to design effective chemical engineering training programmes and fail to ensure the bench strength capable of performing and improving the chemical engineering of the metallurgical processes on an ongoing basis. Consequently, the chemical engineering knowledge operationalization is, frequently, a result of self-learning and trial & error experiences of an individual metallurgist.

2 - Effect Delay of Investments for Growth in Knowledge-Intensive Organizations: An Empirical Study of Information Business
A. D. Amar, Januj Juneja

Not knowing when investments made for the purpose of revenue growth will have their intended effect can hamper management's ability to plan. We study this delay in effect for information business sector by considering association between the investments, revenue growth, and the firm's performance. We do this for annual investments made in R&D, capital expenditure, selling, general and administrative expenses, and property, plant and equipment. By studying four industries in this sector, classified by their SIC codes, we arrive at quantitative variables measuring this effect delay, industry-by-industry and the sector as a whole. Our results are drawn from 88 companies in Computer Programming, Data Processing and Other Computer Related Services sector. In addition to the results on revenue growth, we study effect delay of investments on performance measures of the firm, including cost of sales, earnings before interest and taxes, gross profit, profit margin, cash flow, and times interest earned. We draw inference by formulating hypotheses relating growth strategies using 2,314 cases of decisions covering 39 years, 1980 to 2018, the period that includes many economic cycles. Our results on effect delay show knowledge-intensive organizations how to map their investment decisions for growth. We also find that even though the firms may belong to the same business, effect delay could be different by industry. We give future research directions to expand the learning on growth.

3 - Unlearning: The Invisible Tool for Knowledge Management
Jon Zaidi, Bridget Cameron

Interest in organizational unlearning has rapidly increased as scholars have identified its important links with an organization's knowledge management (KM) and other adaptive capacities (organizational learning and innovation for example). Most research papers provide descriptively rich accounts of unlearning as a "process" but do not satisfy the fundamentals of processual research. Processual research is a specific method of empirical inquiry, which is deeply interested in understanding how an organizational phenomenon (such as unlearning) unfolds and its temporal dynamics. More work is needed to conceptualize unlearning not as a static state or variance, but as a process that unfolds dynamically in time. Part of this work is to understand how unlearning interacts with an organization's KM system. Comprehending how organizations come to identify and subsequently "unlearn" obsolete or misleading knowledge during times of business transformation is a significant gap in business research. This presentation reports on the findings of empirical research undertaken in 2017 at two case sites in Kazakhstan. The study sought to examine the process dimensions of how large corporations with Soviet imprints implement unlearning as an organizational intervention and strategy to support change. The presentation will share the emerging findings of the study and reflect on the ways in which unlearning was found to support or interact with knowledge management processes.

■ MB-20

Monday, 10:30-12:00 - C006

Circular Supply Chains

Stream: Environmental Sustainability in Supply Chains
Invited session

Chair: *Emel Aktas*
Chair: *Gerald Reiner*

1 - Revenue sharing contracts for overcoming trade-offs when establishing circular supply chains
Gerald Reiner, Stefan Gold, Tanja Olip, Boualem Rabta

Establishing circularity in supply chains is often believed to hamper financial and economic business targets. Current developments have underlined those kinds of trade-offs in various industries. For example, smartphone manufacturers are facing related challenges of decreased sales and revenues as customers start keeping their devices longer. Against this background, the main research objective is to investigate incentives across supply chain partners to overcome such trade-offs in order to accelerate the transformation to circular supply chains. For this end, we consider different business models for sustainability as well as business models for circular supply chains. They are evaluated under consideration of value creation capacity, captured value, customer value proposition and environmental value proposition. Inspired by real supply chains we develop a dynamic multistage supply chain model that addresses different usage times (discard rates) like in the mobile phone industry or automotive industry. We investigate how supply chain contract design helps overcoming related trade-offs and thus eliminating obstacles for the implementation of circular supply chains. This research focuses on revenue sharing contracts to create a win-win setting for manufacturers, service providers (retailers, carriers etc.) and consumers to overcompensate potential drawbacks of closing product and material flows, as by repair, reuse, redistribution, refurbishment and remanufacture.

2 - Analysis of incentives in reverse supply chains with asymmetric information
Patricia Rogetzer, Stefan Minner

The increase in innovation and consumption in the electronics industry and companies expanding their e-commerce operations lead to increased amounts of waste. This is in particular true for short life-cycle electric and electronic equipment, such as mobile phones or computers. The idea of reusing the resources from waste streams has led to redefining supply chains based on the circular economy concept and requires proper waste management. A principal of such a community or municipality assigns the task of collecting waste to agents, i.e. companies of the waste disposal industry, based on contracts. An example is the German dual system of waste collection. German manufacturers are by law required to take care of the recycling or disposal of their packaging material. The industry therefore set up a system of waste collection that enables packaging from end-consumers to be picked up in parallel to the existing municipal waste-collection systems, for which manufacturers have to pay a fee (depending on the weight of the returned material). As there is uncertainty involved in the amount of returns and timing, asymmetric information between principal and agents exists. In this research, we analyze by means of a principal-agent model how incentive systems in contracts would have to be structured and how transfer pricing should be used. Managerial insights should help to find the right incentives for the disposal industry to deal with reverse logistics issues.

3 - A production lot sizing model in a circular economy
Boualem Rabta

Circular economy is presented as an alternative to the current linear economic model with the ambition of contributing to the economic growth in addition to having a positive impact on the environment. Companies see opportunities in circular economy business models. It allows the capture of additional values from products and materials that are currently discarded as waste. However, challenges to shift their businesses and products into circular practices still exist. In this work, we investigate the impacts of circular economy product labeling and its use in decision support. In particular, we build a production lot sizing mathematical model taking into account the circularity level of the product and we solve it analytically to determine the optimal parameters. The results illustrate the use of circularity indicators and demonstrate that making circular products can be justified financially from the company's point of view.

4 - Traffic Disruption Influence to Food Quality: The Case of Last-mile Logistics
Valentas Gružauskas, Edita Gimžauskienė, Andrius Kriščiūnas

Growing food demand, tendency for organic food and e-commerce business model adaptation requires new food supply chain management approaches. Current food supply chain approaches are ineffective and wastes 30% of the world produced food. The increasing complexity and dynamic environment is even more negatively affecting the performance of the food supply chains. The goal of this paper is to determine the influence of traffic disruption to food quality in e-groceries. In order to achieve this goal, an agent-based model of last-mile deliveries was developed. The model simulates traffic flow and traffic accidents as disruptions in the system, while measuring food quality of the network. The simulation compares traditional trucks with autonomous trucks in 16 scenarios of last-mile deliveries. The proposed approach promotes information sharing between supply chain members and implementation of cyber-physical systems for tactical and operational level automation, while controlling the strategic level decisions by managers. The usage of autonomous vehicles in the last-mile delivery processes allows developing a self-organizing system, which would adapt to disruptions and would improve food quality levels.

■ MB-21

Monday, 10:30-12:00 - F101

IBM Research Applications

Stream: IBM Research Applications
Invited session

Chair: *Claudio Gambella*
Chair: *Jakub Marecek*

1 - Convex optimisation on quantum computers
Jakub Marecek, Cunlu Zhou

Convex optimisation is a workhorse of operations research. While approximable to any fixed precision in time polynomial in dimensions of the instance on a classical computer, a speed-up is still desirable in many applications. There has hence been much interest in algorithms for quantum computers, which offer a substantial speed-up in some cases. In other cases, there are lower bounds, which show that very little quantum speed-up is possible. We survey the recent results and present a new class of algorithms for semidefinite programming on quantum computers. We showcase their practical performance.

2 - A VQE-based solution approach for applications in mobility services
Claudio Gambella, Andrea Simonetto

Abstract: Ridesharing and mobility services are facing an enormous momentum in terms of distribution and usage. Several optimization problems need to be solved to limit the growth of congestion levels and ensure a cost-efficient allocation of trip requests to vehicles. In this context, routing problems are tackled in real-time implementation, while often sacrificing the search for optimality or large-scale scenarios. Quantum computing may emerge as a potentially appealing alternative to classical computing, in variety of areas, including solving some classes of mathematical optimization problems. One recent near-term application of quantum computers for solving optimization problems is the Variational Quantum Eigensolver (VQE), a hybrid quantum/classical approach. This work proposes some attempts to broaden the applicability of VQE to certain classes of optimization problems. This could enable to exploit the potential of quantum computing to the routing problems arising in mobility applications. The numerical results are conducted via noise-free classical simulation of the quantum circuits implemented in Qiskit.

3 - Quantum Credit Risk Analysis
Stefan Woerner, Daniel Egger, Ricardo Garcia Gutiérrez, Jordi Cahué Mestre, Santiago Murillo Pavas, Joan Francesc Vidal Villalón

We present and analyze a quantum algorithm to estimate credit risk more efficiently than Monte Carlo simulations can do on classical computers. More precisely, we estimate the economic capital requirement, i.e. the difference between the Value at Risk and the expected value of a given loss distribution. The economic capital requirement is an important risk metric because it summarizes the amount of capital required to remain solvent at a given confidence. We implement this problem for a realistic loss distribution and analyze its scaling to a realistic problem size. In particular, we provide estimates of the total number of required qubits, the expected circuit depth, and how this translates into an expected run time under reasonable assumptions on future quantum hardware.

4 - Prediction-Optimization Methods for Process Industries
Pavankumar Murali

With the advent of Industry 4.0 and the vast amount of sensor data generated in manufacturing and process industries, there is an opportunity to produce AI-driven advisory support for plant managers. However, current industry practices include very limited use to such techniques to devise an optimal time-indexed operational plans. For instance, process industries typically resort to first-principles or a process simulator to represent behavior of various unit processes within a plant. In our work, we rely on a well-trained data-driven model to represent plant behavior. Using historical time-series data for model training, offers higher model fidelity and better predictive power under varying operational conditions. Operational plans need to be dynamic to changing operational conditions, and managerial and economical priorities, thereby requiring the ability to capture run-time behavior of each process and alter any set-point controls as needed. We present a novel solution based on the use of machine learning to learn process relationships from sensor data. We couple the resulting data-driven models with optimization techniques to develop a site-wide optimization advisor. We illustrate the application and effectiveness of the proposed framework with a case study based on oil sands processing industry.

■ MB-22

Monday, 10:30-12:00 - F102

Scheduling Models for Complex Manufacturing Systems

Stream: Production Planning and Control for Complex Manufacturing Systems
Invited session
Chair: Udo Buscher
Chair: *Janis Sebastian Neufeld*

1 - Multi-Objective Unrelated Parallel Machine Scheduling to Minimize Total Tardiness and Energy Cost
Söhnke Maecker, Liji Shen

The energy cost aspect in machine scheduling is gaining growing attention due to its high relevance especially in energy-intensive manufacturing industries. For large businesses in countries with developed energy markets, the cost of electricity, often, is not driven solely by the amount consumed, but also by the time at which it is used. In the pricing schemes known as time-of-use (TOU), companies pay in advance for electricity at a centralized energy market. Therefore, immense cost savings can be realized by considering this aspect in production scheduling decisions. In our study, we aim at integrating electricity costs in the classical time-based criteria. To be precise, we consider an unrelated parallel machine scheduling problem, where the objectives are to minimize the total tardiness of jobs as well as the total energy cost (TEC) of the schedule. Since machines are assumed to be heterogeneous, the problem also includes different energy consumption rates of machines. The TEC is then calculated based on a TOU pricing scheme. For this NP-hard problem, we formulate a multi-objective mixed integer linear program which is tested on a set of randomly generated instances. Furthermore, to obtain an optimal Pareto Front for small-scaled instances, we apply an augmented e-constraint method to show the trade-off between the two objectives.

2 - Exact and Heuristic Approaches for Parallel Machine Scheduling with Machine-dependent Delivery Times
Liji Shen, Lars Moench

In this talk, we consider a parallel machine scheduling problem where machine-dependent delivery times exist for each job. Such problems arise in distributed manufacturing. Each job has a weight that represents the importance of the job. The service time of a job is defined as the time that is needed to deliver the job to the customer. We are interested in minimizing the total weighted service time. We start by presenting a Mixed Integer Linear Programming (MILP) formulation for this problem. We then analyze several special cases. We propose a genetic algorithm (GA) and a greedy randomized adaptive search procedure (GRASP) for the general case that is NP-hard. Computational experiments based on randomly generated problem instances demonstrate that the GRASP outperforms the GA with respect to solution quality and computing time.

3 - A MIP-formulation for integrated production and outbound distribution scheduling with site selection
Udo Buscher, Eduardo Alberto Alarcon Gerbier

In order to meet customers' demands for ever shorter delivery times, two main approaches are pursued. On the one hand, there is the possibility of following the distributed manufacturing concept and organizing production more decentralized. The aim is to relocate the production sites close to demand in order to reduce transport times and costs. On the other hand, there are attempts at a more operational level, to integrate production scheduling and distribution planning in order to deliver products on time at the lowest possible cost. As a result, the products are often delivered directly after production without stock keeping. In the literature, this problem is referred to as the integrated production and outbound scheduling problem. The location routing problem is an approach that considers location issues together with distribution planning. However, production scheduling is completely neglected. This paper tries to address this research gap by bringing both problems together. First, a mixed-integer programming model is set up, implemented in CPLEX and illustrated with a numerical example. The model is subsequently extended by several planning periods, including the consideration of relocation costs.

4 - A MIP model for Hybrid Flowshop Scheduling with Tooling Constraints
Janis Sebastian Neufeld

Resource constraints are relevant for many practical scheduling problems and have been widely investigated in literature, in particular for single-stage systems and job shop environments. We discuss a multi-objective hybrid flowshop scheduling problem that integrates a new type of resource constraint regarding a limited availability of tools. Its main characteristics are that specific tools are necessary for certain tasks and after a defined useful life each tool has to be renewed. These maintenance and repair processes lead to additional costs, which are integrated into the objective function. Besides, total flow time is minimized. We propose a mixed integer linear programming model (MILP) for the considered problem. The MILP is solved for several test instances using CPLEX. Furthermore, epsilon method is applied to gain pareto optimal solutions and analyze the structure of the problem.

■ MB-23

Monday, 10:30-12:00 - F103

Omni-Channel and Online Retailing

Stream: Demand and Supply Management in Retail and Consumer Goods
Invited session
Chair: Heinrich Kuhn

1 - Omni-channel Grocery Retailing: An Approach for Multi-Depot Order Fulfillment
Alexander Hübner, Christian Dethlefs, Manuel Ostermeier

Establishing functioning omni-channel environments is one of the main retail challenges today. Due to the competition through online retailing, a mere focus on offline sales is not competitive anymore. Traditional retailers own a wide network of stores and distribution centers (DCs) but struggle when merging offline and online operations. Advantages and disadvantages of existing offline depots need to be combined wisely. While picking orders is more efficient in DCs, transportation costs are lower and customer service levels are higher for local stores in close customer proximity. Further, each depot offers different delivery options due to heterogeneous vehicle fleets and product availability. This trade-off between depot types constitutes an essential decision for efficient order fulfillment concepts. We present a variant of the multi-depot vehicle routing problem (MDVRP) to address this problem for the order fulfillment in grocery distribution. We identify decision relevant costs for the order processing in each depot type and enable a realistic evaluation of overall fulfillment costs. The presented MDVRP simultaneously considers the order assignment to heterogeneous depots and the vehicle routing for each depot. Both subproblems are highly interrelated as order assignment decisions directly affect the routing. We therefore develop a tailored, integrated solution approach.

2 - Order Fulfillment Policies for Ship-from-Store Implementation in Omni-Channel Retailing
Bahriye Cesaret, Armagan Bayram

Omni-channel retailing is a fully integrated approach that allows customers to purchase products from anywhere and return them anywhere and allows retailers to fulfill orders from anywhere, thus offering customers more flexibility and a unified shopping experience. Omni-channel retailing unlocks tremendous opportunities for a retailer to leverage its store network to support its online sales. One of these opportunities is ship-from-store which allows a retailer to fulfill online orders by using inventory from a nearby brick-and-mortar store.

In this study, we consider a retailer having both online and store operations, with each channel carrying its own inventory. Store orders are fulfilled from store inventories, whereas an online order can be shipped either from an online fulfillment center or from any other store location that maximizes the retailer's overall profit. Our study investigates dynamic fulfillment decisions: from which location to fulfill an online order when it arrives. We incorporate the uncertainty both in demand and in the cost of shipment to individual customers. We develop a stochastic dynamic framework and characterize the optimal cross-channel fulfillment policy.

3 - Customer behavior under risk: evidences from online grocery retail
Pedro Amorim, Catarina Pinto

Lack of picking control and delivery errors are factors that increase customers' perceived risk in online grocery shopping (Hansen, T. (2006), Ramus, K et al (2005)). Due to high failure rates, customers commonly receive orders that differ from their purchases. Based on Prospect Theory, the "playing safe effect" and other decision-making under risk theories, we model the impact of this failure-related risk on customers' spending. We show that prior and recent failures affect spending negatively, with an emphasis on recent failures (up to 40% decrease). We further note that habit makes customer less sensible to failure-related risk. Our findings are in scope with other scenarios of decision-making under risk, such as horse betting and online gambling.

4 - The impact of stockouts on customer churn in online grocery retail
Gonçalo Figueira, André Campos, Pedro Amorim

Customer retention is one of the most important challenges that retailers have been facing, as customer acquisition is roughly five to six times more expensive, and long-term customers generate higher profits. In online retail, retention is particularly challenging since customers experience no switching costs and can easily compare offers and prices. The literature has studied the issue of customer retention, but the existing studies have essentially used demographics and behavioural variables, such as the so-called 'recency, frequency and monetary' (RFM) variables. The obtained results can help the marketing department target promotions and other activities to improve retention. We, on the other hand, look at this problem from the lens of operations management. Contrarily to traditional retail, in online retail all demand, including that which is unfulfilled, is read. By introducing order fulfilment variables, such as stockouts and substitutions, in our churn prediction models, we seek to derive actionable insights for operations managers. We test both Logistic Regression and Gradient Boosting Machines on our online grocery dataset. Results confirm that substitutions are an important mechanism to reduce churn, and that the service level of durable goods is more important than that of fresh products.

■ MB-24

Monday, 10:30-12:00 - F103A

Network analysis of supply chains

Stream: Supply Chain Management
Invited session
Chair: Maxi Udenio

1 - The Cash Conversion Cycle: An Empirical Analysis of its Impact on Supply Chain Performance
Shaunak Dabadghao, Maxi Udenio

This study examines the effects of working capital management practices (e.g. changes in accounts payables or accounts receivables) on the performance of a firms' supply chain partners. We collate quarterly data from the COMPUSTAT database and construct over 1900 customer-supplier dyads using over 30,000 quarter observations from 1980 to 2015. We empirically determine how changes in the Cash Conversion Cycle (CCC) of a firm impacts the performance and the CCC of its supply chain partners. We find that dyads in which both firms are improving their CCC perform better than others. These findings contribute to the research on working capital management strategy by identifying successful supply chain relationship practices in terms of firm performance.

2 - Evolution of Supply Networks
Maxi Udenio, Nikolay Osadchiy, Vishal Gaur

The last four decades have witnessed a radical transformation of production and trade. Both have become more globalized. Yet, as the trade flows connected different parts of the world, production processes have become more dispersed across firms and countries. The present day production is a carefully choreographed act involving multiple firms supplying raw materials and finished components from around the country and globally. This process is called vertical specialization or fragmentation of production. In this paper, we seek to quantify fragmentation in supply chains and understand factors associated with it.

3 - Planning of Modular Production Networks for the Specialty Chemicals Industry
Brigitte Werners, Tristan Becker, Bastian Bruns, Stefan Lier

The chemical industry is facing new challenges due to shorter product life cycles and greater diversification of the product portfolio. Modular production concepts are evaluated to cope with the increased variability in customer demands. Modular plants consist of standardized process modules installed in containers, which enable fast assembly, disassembly and relocation of production plants. Depending on the combination of process modules, different production capabilities are associated with a production plant. Modular production plants can be operated in industrial or chemical parks. It is therefore possible to increase the efficiency of the logistic network by operating modular plants close to customers or suppliers. We present a case study from the specialty chemicals industry in which specialized polymers are produced by mixing base polymers with various additives. New mixed integer programming formulations for production network planning under consideration of the new flexibility options of modular production concepts are presented. On the basis of real data from a large chemical company, we discuss the economic benefits of production in close proximity to suppliers and customers for the specialty polymers market. In addition, the advantages of different process layouts for modular plants are compared.

■ MB-25

Monday, 10:30-12:00 - F104

Cutting and Packing 2

Stream: Cutting and Packing
Invited session
Chair: *A. Miguel Gomes*

1 - A Survey on Data Mining approaches to Cutting & Packing problems
A. Miguel Gomes

This talk presents a brief survey of Data Mining approaches to Cutting & Packing problems. The main focus is to study and explore connections between traditional Cutting & Packing approaches and Data Mining (and Machine Learning) ones. The aim is to provide new insights on Cutting & Packing problems to develop new hybrid solutions.

2 - Two-dimensional rectangular bin packing problem in glass industry
Shinji Imahori

We study a two-dimensional bin packing problem which efficiently cuts out given rectangular products from rectangular base materials of the same size. This problem is an important combinatorial optimization problem in manufacturing industries such as glass and steel. In glass industry, as stated in "ROADEF/EURO Challenge 2018: Cutting optimization problem" in collaboration with Saint-Gobain, a wide variaty of constraints should be considered for practical usage. In this talk, we mainly consider the k-stage guillotine cut constraint and defects on the base materials, where rectangular products should be cut from the base materials by at most k consecutive end-to-end cuts and defects must not be involved in any products. For the problem, we first design construction heuristic algorithms. We also state local search techniques which improve the given layouts of products with slight modification. To design efficient local search algorithms, how to represent a solution and how to evaluate them are key issues. We use a tree representation corresponding to product layouts given by consecutive guillotine cuts and analyze its usefulness in local search algorithms.

3 - Matheuristics for a real-world leather industry cutting problem
Antonio Martinez Sykora, Tony Wauters

This work considers a leather industry cutting problem. The addressed problem, referred to within the literature as nesting in terms of category, is a two-dimensional cutting (and packing) problem where irregular and nonconvex pieces of material must be cut from the hides. The goal is to minimize the amount of wasted material incurred during the cutting of such pieces. Nesting problems such as the leather industry cutting problem are very relevant in practice, but the quantity of research dedicated to them is low when compared against other (more classical) cutting and packing problems. Previous researchers in the area have highlighted that this is primarily a result of the inherent difficulty involved in the implementation of the necessary geometric algorithms. The present work formulates the leather industry's nesting problem as a mixed-integer program. All problem characteristics are addressed, such as quality zones and holes. The resulting formulation, however, cannot be solved by state-of-the-art solvers when real-world instances are considered, stimulating the investigation of heuristic alternatives. The present research considers both constructive and local search (math)heuristics employing the proposed formulation. Different strategies and parameters are evaluated with regard to both performance and quality, and the obtained results are compared against the state-of-the-art in the literature.

4 - Packing and scheduling of locks through the Three Gorges and Gezhouba Dams
Julia Bennell, Xiaopan Zhang

The Three Gorges Dam and the Gezhouba Dam reside on the Yangtze River in Hubei province in China. Almost 200 million tonnes of freight pass through the Dams annually. The Dams are 38km apart. Given the volume of freight passing through the dams, it is important to coordinate the scheduling of vessels through both the dams. The Three Gorges Dam has two locks, one services downriver vessels and the other servicing upriver and a ship lifter to transfer vessels less than 3000 ton over the TG Dam one by one, while Gezhouba Dam has three locks of different sizes that can service both upriver and downriver vessels. The objective is to maximise the volume of freight passing through the dams while meeting fairness constraints. The problem is modelled as a two dimensional bin packing problem where the small items are vessels and the bins are the locks. Since the ship lifter carries a significantly smaller capacity than the locks, so we can ignore it in our model. Bins have a processing time where the next bin representing a given lock can only be processed once the previous bin is complete. Moreover, we can only pack a small item in the bin once they have reached the bin on its journey. We formulate the problem as a mixed integer programme and test the capability of the model in terms of the size of problems it can solve. We also consider how to solve bigger problems.

■ MB-26

Monday, 10:30-12:00 - F106

Queueing Games

Stream: Service Operations Management
Invited session
Chair: *Ping Cao*
Chair: *Caner Canyakmaz*

1 - Priority Service Pricing with Heterogeneous Customers
Ping Cao, Yaolei Wang, Jingui Xie

This paper studies a pricing problem for a service system, in which customers have heterogeneous delay sensitivity. The system sets priorities for customers and gains profit by charging a price for priority service. The service system consists of a single server and two queues, in which customers in the first queue are given priority. Customers have a heterogeneous delay cost rate, which is drawn from a general distribution. Upon arrival, the customer must decide which queue to join. If the customer joins the priority queue, a fixed priority price will be charged. We discuss customers' choice behavior under any given priority price, and find that there can be multiple equilibria, the number of which depends on the distribution of customers' delay cost rate. In addition, we characterize the stability of these equilibria, and show that the system can always reach the largest or smallest equilibrium by setting a proper initial delay announcement. We also consider optimal pricing problems with the objective of maximizing the system's long-run average profit and social welfare. Our results demonstrate that optimal prices depend on the distribution of customers' delay cost rate.

2 - Estimating Patience with Silent Abandonment
Antonio Castellanos, Galit Yom-Tov, Yair Goldberg

Customer (Im)Patience has proven to be a significant factor in modeling service systems and making staffing decisions. A customer who is waiting for service in a queue has finite patience and might abandon. Abandonments have been regarded as uni-type; However empirical evidence from contact centers has contradicted this assumption, which enables us to classify them into two groups: known and silent abandonments. Known abandonment appears when the customer gives a clear indicator that she just left (patience time is observed). In contrast, silent abandonment occurs when a customer left the system, but the service provider is unaware of that fact until the agent communicates with the customer and receives no reply (patience time is left censored). Notice that in silent abandonments some server time is wasted until abandonment is realized; for this reason, they should be considered when making staffing decisions. In the current research, we propose a queuing model with silent abandonments for two environments: one where we know exactly which customer silently abandoned the queue and another where we are unable to clearly distinguish these customers from customers that had very short service (i.e. finished service in a single interaction). We develop a prediction model to classify customers in the second case and develop estimators of customer patience for both environments. We discuss how silent abandonment influences performance measures and and staffing recommendations.

3 - Opaque queues: Service systems with rationally inattentive customers
Caner Canyakmaz, Tamer Boyaci

Many service systems in practice are arguably opaque or only "partially visible" in the sense that customers are not always able to discern precise queue lengths upon arrival. This stems mainly from potential information frictions due to the physical environment and/or cognitive capabilities of customers. Determining the exact queue size requires attention and cognitive capacity (and time), which are all limited in quantity. We capture the salient features of rational queueing behaviour under limited customer attention through rational inattention framework. Customers optimally select the type and quantity of information they need and ignore the information that is not worth obtaining in a completely endogenized information acquisition process, trading-off the benefits of better information against the cost associated to it (measured as the reduction in Shannon entropy). In a service system with inattentive customers, beliefs about the queue size distribution are shaped by both endogenously optimized information processing strategies and resulting joining decisions of other inattentive customers in equilibrium. We show that such an equilibrium exists and that it is unique. We also investigate the impact of information cost and characterize its implications regarding information provisioning strategies of firms. Our unifying framework retrieves existing results for visible and invisible queues in extant literature as special cases.

■ MB-27

Monday, 10:30-12:00 - F107

Network Optimization

Stream: Telecommunications and Network Optimization
Invited session
Chair: Lovis Anderson

1 - Capacitated Network Design for Resource Planning using Annealing Method
Jonas Christoffer Villumsen, Takuya Okuyama

Digital and quantum annealers have recently emerged as a new computing architecture for many combinatorial optimisation problems based on the Ising model. We propose a novel formulation of the capacitated network design problem as a quadratic unconstrained binary optimisation problem (QUBO). The QUBO formulation enables the solution of capacitated network design problems by minimising an Ising Hamiltonian on digital and quantum annealers such as the D-Wave 2000Q and Hitachi's CMOS annealing machine. Annealing machines and algorithms hold the potential for efficiently solving NP-hard problems by implementing a physical process which emulates the ground state search of an Ising model. We solve the capacitated network design problem on Hitachi's annealing technology in combination with a standard LP-solver. Preliminary results are promising showing that the capacitated network design problem can be solved on annealing machines in reasonable time. This provides hope that large-scale network design problems in the future can be solved efficiently on specialised computing architectures. Research is ongoing to improve solution speed, accuracy, and scale of problems that can be solved. The solution of capacitated network design problems is motivated by the application to capacity and resource planning in smart spaces. We describe the problem of allocating resources to activities within a smart space and provide the network design formulation.

2 - Benchmarking tree approaches on street data
Fabion Kauker

By examining the use of algorithms to solve the Prize Collecting Steiner Tree (PCST) problem we consider the facets which determine effectiveness. Specifically, by measuring a number of solution approaches and comparing them based on metrics. In order to understand the solution approach we must asses why it is useful. Our goal is to determine the effectiveness of Mixed Integer Programming (MIP) and heuristic methods. Utilizing freely available street and address data a base graph representation is created and then computed on. Such that a tree connects every address utilizing the minimum total length of edges from the street network. This is the basis of many approaches used to solve infrastructure problems including telecommunications network design and costing. The analysis is conducted on methods developed by Hedge et al. 2015, Ljubić et al. 2006, and Teitz et al. 1963. We present a data processing architecture, as well as a concise set of results and a framework for assessing the facets and trade-offs for a given approach. In this case the heuristic approaches are proven to have advantages in the simplistic case but fail when more complex requirements are added. This is where the MIP approach is able to capitalize, whilst detrimentally limiting the flexibility due to the strictness and specificity in modelling.

3 - Decision Making within Navi Stations of a Gas Network
Lovis Anderson, Felix Hennings

The NAVI is an optimization tool for the highly complex German gas network that is under development at Zuse Institute Berlin in cooperation with the gas transportation company Open Grid Europe. The purpose of the NAVI is to be an assistance tool for dispatchers, which similar to the navigation system in a car or a phone, creates recommendations and plans for the future. Due to the physical properties of gas this leads to a non-convex and non-linear transient problem. To cope with that complexity we use a two-stage approach to fit the gas network to the forecasted supplies and demands. In the first stage we solve a rather coarse model which fixes the flow directions and the flow on groups of critical nodes in the network. In the second part, the station model, we take a more detailed view on navi stations, the hubs of the network. Navi stations are dense subnetworks with many active elements that are found at important intersections of the trans-regional gas network. The decisions that we make within a navi station, are the modes and operating points of all active elements, namely control valves and compressor stations, which we model with target values and characteristic diagrams respectively.

■ MB-28

Monday, 10:30-12:00 - G102

Risk Analysis and Management 1

Stream: Decision Making Modeling and Risk Assessment in the Financial Sector

Invited session

Chair: *Erik Winands*

1 - Household Portfolio Optimization with XTFs? An Empirical Study Using the SHS-base

Hans Philipp Wanger, Andreas Oehler

XTFs are plain-vanilla Exchange Traded Funds (ETFs) which replicate a broad, internationally diversified market index. As households' investment portfolios often reveal suboptimal diversification, a common recommendation to households is to employ XTFs. We investigate, if this recommendation can generally optimize the risk/return-relation of households' portfolios. First, we estimate risk/return-relations for stylized asset allocation clusters of households, so called Household Portfolio Types (HPTs). Therefore, we combine two data sets by Deutsche Bundesbank: The Panel on Household Finances (PHF) and the Securities Holdings Statistics (SHS)-base. We find three HPTs with different asset class concentrations. Second, we risk-adjust HPTs and the benchmark XTF portfolio to each other and measure return differences to assess XTFs' potential to enhance HPTs' returns under consideration of (de-)leveraging costs. Return differences indicate that XTFs reveal potential to enhance the returns of all HPTs. Third, we adjust each HPT with the benchmark XTF portfolio. Hereby, we include transaction costs. The adjustment of HPTs with XTFs can, depending on the regarding HPT, reduce risk and increase return, predominantly enhance returns or reduce portfolio risk, respectively.

2 - Portfolio Risk Management Using Statistical Process Control

Robert Mefford

Statistical Process Control (SPC) has been extensively used for quality control in a wide range of manufacturing and service organizations but has not been applied to investment portfolio management. In this paper the potential application of SPC to allocation and risk management of investments is explored. SPC can be used to identify a shift in market sentiment which in turn can signal to investment managers to change portfolio allocations to-or-from riskier assets and/ or to employ hedges. Measures of investment sentiment and jump risk are tested for their forecast capabilities using equity market data. Process control charts are then developed from the empirical data. How the SPC charts can be employed to improve portfolio performance in terms of improving returns and reducing risk are discussed.

3 - Naïve diversification in thematic investing - Heuristics for the core-satellite investor

Florian Methling, Rüdiger von Nitzsch

In recent years, thematic exchange-traded funds (ETF) have given core-satellite strategies a new impetus by attracting much attention of both institutional and retail investors. Thematic investing attempts to participate in certain trends, or to serve any conceivable subjective interest such as ethics and sustainability. An elaborate optimization of a thematic portfolio by purchasing individual assets is very costly, and ETFs are not customizable for private investors. Therefore, thematic ETFs are supplemented to conventional ones to suit additional non-monetary interests. Hence, the question arises how to weight the thematic satellite in relation to the diversified core portfolio. Complex research and factor models are hardly suitable for private investors and the short history of thematic products would not provide reliable information anyway. Therefore, new ideas have to be examined - or perhaps old ones? The Talmud contains a 1,500-year-old allocation rule that has already been investigated by several studies under the name of naïve portfolio diversification. However, this study develops naïve diversification for thematic core-satellite investors. Furthermore, minimum concentration is established as an allocation rule based on the Herfindahl index. The provided heuristics prove to be useful and competitive compared to a minimum-variance optimization in out-of-sample tests. Hence, this study offers some pragmatic and truly practical aid for thematic investors.

4 - Capital reserve management for a multi-dimensional risk model

Erik Winands

Firms should keep capital to offer sufficient protection against the risks they are facing. In the insurance context methods have been developed to determine the minimum capital level required, but less so in the context of firms with multiple business lines including allocation. This research focuses on the calculation of finite-time ruin probabilities and capital reserves for a multi-dimensional risk model. The individual reserves of these lines of business are modeled by means of a Cramér-Lundberg model with constant incoming premiums and outgoing claims that arrive according to a Poisson process. To allow for dependence between business lines we introduce a common (latent) environmental factor. This environmental factor impacts the claim inter-occurrence times as well as the claim sizes. Considering a fixed environmental process over time, we present a novel Bayesian approach to calibrate the latent environmental state distribution based on observations concerning the claim processes. We then we allow for the distribution of individual claims to change over time by using a Markov environmental process. For the latter, we present two approximations for the finite-time multi- variate survival/ruin probabilities: a diffusion approximation and a single-switch approximation. Finally, we point out how to determine the optimal initial capital of the different business lines under specific constraints on the ruin/survival probability of subsets of business lines.

■ MB-29

Monday, 10:30-12:00 - C118

VNS metaheuristics and Matheuristics

Stream: Metaheuristics

Invited session

Chair: *Eduardo G. Pardo*

Chair: *Angelo Sifaleras*

Chair: *Floor Verbiest*

1 - A Heuristic for the Traveling Salesperson Problem with Forbidden Neighborhoods on Regular 2D and 3D Grids

Philipp Armbrust, Philipp Hungerländer, Anna Jellen

In this work a heuristic for the Traveling Salesperson Problem with Forbidden Neighborhoods (TSPFN) is introduced. Given a regular grid and a radius r, the TSPFN asks for a shortest Hamiltonian cycle over all grid points such that the distance between consecutive points is greater than r. This TSPFN is motivated by a real world application called laser beam melting. This technology is used for building complex workpieces in several layers, similar to 3D printing. In previous works we determine the length and structure of optimal solutions. The introduced heuristic is based on Warnsdorff's Rule and able to deal with instances where no closed-form solutions are known. The main differences to the original Warnsdorff's Rule can be summarized as follows: (1) Arbitrary step sizes are allowed, in contrast to the fixed step size of length square root of five in the original Warnsdorff's Rule. (2) The resulting solution must be a Hamiltonian cycle instead of a Hamiltonian path. (3) The step size is not fixed: if some squares are still unvisited but not reachable with the currently selected step size, our heuristic increases the step size such that the next square can be reached. We implemented the heuristic and conducted a computational study for various neighborhoods. In particular, the heuristic is able to find high quality TSPFN tours on 2D and 3D grids, i.e., it produces optimum and near-optimum solutions and shows a very good scalability also for large instances.

2 - GRASP and Multiple Neighborhood Search for real vehicle routing problem.

Flavien Lucas, Gwénaël Rault, Romain Billot, Philippe Lacomme, Marc Sevaux

For a few decades vehicle routing problems have been studied and improved, it includes today many features under the common denomination of rich vehicle routing problems. In our study, multiple types of vehicles are considered, including fixed cost, variable cost, velocity and capacity. The topology of these instances includes restrictions on the graph for some types of vehicles. Instances based on real road maps take into account some specificity like asymmetric graph, triangular inequality not respected, forbidden turns depending on crossroad and congestion information that impact the solving methods. Very large scale instances with thousands of customers are solved using a GRASP and a multiple neighborhood search method to obtain high quality solutions in reasonable execution time. The GRASP is based on the so-called Clarke and Wright heuristic and the multiple neighborhood search method presents an unified view of several classical neighborhoods. The solution method has been particularly improved to handle the very large scale instances.

3 - The strategic design of multiproduct batch plants: the application and analysis of a matheuristic solution technique

Floor Verbiest, Trijntje Cornelissens, Johan Springael

In this study, we present a matheuristic for the strategic batch plant design problem with parallel production lines. The aim of this MILP problem is to minimize capital, startup and contamination costs through the optimization of 3 decisions: the number of lines to install on the plant, their design (i.e. number and size of equipment units for every production stage), and the assignment of products and production quantities to the installed lines. These different types of decisions lead to a natural separation of the global problem into subproblems, each of which can be solved with adequate solution methods. More specifically, we applied an iterative local search (ILS) metaheuristic for the discrete design decisions for every stage of every line, whereas the product-to-line assignments are optimized with an exact MILP solver. Additionally, we analyzed the search process of the matheuristic to obtain some insights into, first, the operation of the different components and, second, the impact of the different cost elements.

4 - Metaheuristics for the two twin cranes scheduling problem

Eva Vallada, Avelino Ferrer, Fulgencia Villa

In this work, we propose methods to optimise the movements of two twin cranes that operate together in a container block and have to carry out a series of storage and retrieval requests both from the sea and land side. The cranes can not cross each other and must keep a safety distance. The objective is to minimise the total completion time of the requests. The proposed solution consists of a genetic algoritmo combined with a constructive heuristic. Different versions of the algorithm are obtained and their parameters have been tuned by extensive computational experimenta. The performance of the proposed algorithms is analysed by means of an Analysis of Variance.

■ MB-30

Monday, 10:30-12:00 - C007

The Role of Mathematical Optimization in Data Science I

Stream: Data Science Meets Optimization
Invited session
Chair: *Vanesa Guerrero*

1 - Combinatorial Optimization for Image Segmentation and Large Scale Data Mining

Dorit Hochbaum

The dominant algorithms for machine learning tasks fall most often in the realm of AI or continuous optimization of intractable problems. We present combinatorial algorithms for machine learning, data mining, and image segmentation that, unlike the majority of existing machine learning methods, utilize pairwise similarities. These algorithms are efficient and reduce the classification problem to a network flow problem on a graph. One of these algorithms addresses the problem of finding a cluster that is as dissimilar as possible from the complement, while having high similarity within the cluster. These two objectives are combined either as a ratio or with linear weights. This problem is a variant of normalized cut, which is intractable. The problem and the polynomial-time algorithm solving it are called HNC (Hochbaum's Normalized Cut). An extensive empirical study demonstrates that incorporating the use of pairwise similarities improves accuracy of classification and clustering. To address the quadratic rate of growth in the size of the data with the use of similarities we employ "sparse computation". It is shown that using "sparse computation" enables the scalability of similarity-based algorithms to very large-scale data sets while maintaining high levels of accuracy. We demonstrate several applications of variants of HNC for data mining, medical imaging, and image segmentation tasks, including the use of HNC for cell identification in neuroscience datasets.

2 - Mixed Integer Nonlinear Programming for Feature Selection in DEA

Sandra Benítez-Peña, Peter Bogetoft, Dolores Romero Morales

In this talk we present an integrative approach to feature selection in Data Envelopment Analysis (DEA) for Benchmarking. DEA aims at benchmarking the performance of decision marking units (DMUs), which use the same inputs and produce the same outputs, against each other. In Data Envelopment Analysis, the efficiency of DMUs is measured as the weighted summation of the outputs divided by the weighted summation of the inputs, and the weights are found solving a Linear Programming problem for each DMU. DMUs with a score equal to one are in the so-called efficient frontier. Feature selection for both outputs and inputs has a significant impact on the shape of the efficient frontier, as well as the insights given to the inefficient DMUs. Here, the DEA model is enriched with zero-one decision variables modelling the selection of features, yielding a Mixed Integer Nonlinear Programming formulation. This single-model approach can handle different objective functions as well as constraints to incorporate desirable properties from the real-world application. Numerical results will be presented using data from Electricity Distribution System Operators. Such results highlight the advantages that our single-model approach provide to the user, in terms of making the choice of the number of features, as well as modeling their costs and their nature.

3 - Sparsity and Performance Enhanced Markowitz Portfolios Using Second-Order Cone Programming

Noam Goldberg, Ishy Zagdoun

A mixed-integer second order cone program (MISOCP) formulation is proposed for solving Markowitz's asset portfolio construction problem under a cardinality constraint. Compared with a standard alternative big-M linearly constrained formulation, the proposed reformulation is shown to be solved significantly faster using state-of-the-art integer programming solvers. We consider learning methods that are based on the MISCOP formulation: cardinality-constrained Markowitz (CCM) solves the MISCOP for a given cardinality k and training set data of asset returns. We also find reinforcing evidence for factor model theory in the selection of factors to form optimal CCM portfolios. For large datasets in the absence of a hard-cardinality constraint, we propose a method (CCM-R) that is based on the continuous relaxation of our MISCOP, where k selected by rolling time window validation. In predictive performance experiments, based on historical stock exchange data, our learning methods usually outperform a competing extension of the Markowitz model that penalizes the L1 norm of asset weights.

4 - Optimal Arrangements of Hyperplanes for Multiclass SVM-Based Classification
Víctor Blanco, Alberto Japón Sáez, Justo Puerto

We present here a novel approach to construct multiclass classifiers by means of arrangements of hyperplanes. We propose different mixed integer non linear programming formulations for the problem by using extensions of widely used measures for misclassifying observations in binary Support Vector Machines. We prove that kernel tools can be extended to these models. Some strategies are detailed that help solving the associated mathematical programming problems more efficiently. An extensive battery of experiments has been run which reveal the powerfulness of our proposal in contrast to other previously proposed methods.

■ MB-31

Monday, 10:30-12:00 - G108

Capacity planning in healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Inês Marques*
Chair: *Sally Brailsford*

1 - Hybrid heuristic for the patient-bed allocation problem
Fabian Schäfer, Alexander Hübner, Dominik G Grimm

Managing patient to bed allocations is an everyday task in hospitals. In recent years it has moved into focus due to a general rise in occupancy levels and the resulting need to efficiently manage tight hospital bed-capacities. This holds true especially for large maximum-care hospitals, which are by definition obliged to treat any incoming patient. Hence, maximum-care hospitals exhibit a high ratio of emergency patients as well as a high volatility and uncertainty regarding patient arrivals and lengths of stay. The patient-bed allocation problem (PBA) decision support model refined the patient admission scheduling problem (PAS) by means of a real-world situation in a large maximum-care hospital. The PBA identifies three main stakeholders, namely patients, nursing staff, and doctors, whose individual objectives and constraints lead to a potential trade-off situation. Due to the combinatorial complexity of the PBA, there is a need for a heuristic that intelligently assists the bed manager in taking fast decisions and is able to deal with uncertain situations through quick recalculations. Therefore, we developed a hybrid heuristic based on a preferred iterative look ahead technique and a genetic algorithm. Furthermore, to deal with the high volatility and uncertainty of emergency admissions, we trained a deep neural network to forecast emergency occupations based on features related to time designation, weather, fairs, and holidays.

2 - Supporting joint operating room and ICU planning with optimisation and simulation approaches
Sebastian Rachuba, Lisa Imhoff, Khairun Bapumia, Brigitte Werners

Operating rooms (ORs) are an important cost and revenue centre in hospitals. The utilisation of ORs also affects downstream resources such as Intensive Care Units (ICUs) or inpatient wards. Simultaneous planning of OR and ICU utilisation can lead to beneficial effects on both bed occupancy and OR time utilisation. We present a mixed-integer linear optimisation model for tactical decision-making. The model decides upon the number of surgeries to be planned in a typical week considering the scarce resources OR time and ICU beds. In order to evaluate this tactical decision, we develop a discrete event simulation (DES) model that replicates the activities on an operational level stochastically simulating daily activities in the operating theatre and the ICUs. We demonstrate the beneficial combination of optimisation and the DES model in a series of computational experiments. Finally, we discuss managerial implications which can be drawn from this planning approach.

3 - Optimizing interventions across the HIV continuum of care: Process improvement analysis
Margaret L. Brandeau

UNAIDS' 90-90-90 goal for 2020 is for 90% of HIV-infected people to know their status, 90% of infected individuals to receive antiretroviral therapy (ART), and 90% of those on ART to achieve viral suppression. To achieve talk we show how HIV care can be improved by viewing the patient care process as a production process and applying methods of process improvement analysis. We examine the HIV continuum of care at a hospital-based HIV clinic in Kingston, Jamaica. We perform qualitative analysis to identify key programmatic, personnel, and clinical areas for process improvement. We then perform quantitative analysis: We develop a stochastic model of the care process which we use to evaluate the effects of potential process improvements on the number of patients who receive ART and the number who achieve viral suppression. We also develop a model for optimal investment of a fixed budget among interventions aimed at improving the care cascade and we use the model to determine the optimal investment among three interventions that the clinic could invest in. By viewing the patient care process as a production process and applying qualitative and quantitative process improvement analysis and an innovative optimization methodology, our approach can help patient care clinics identify the best ways to maximize clinical outcomes.

4 - Operating room time allocation to surgical services: the case of a public hospital in Portugal
Mariana Oliveira, Inês Marques, Luisa Lubomirska

Operating rooms (ORs) are challenging services for hospitals: large cost center because it handles expensive technology, equipment, materials and high specialized staff; has large impact in the workload of several up- and downstream units; faces increasing demand and large waiting lists; and deals with powerful and often conflicting stakeholders. Facing restrictive budgets, the OR manager needs to use resources flexibility to match surgical supply with the ever-increasing demand which can be achieved through OR time distribution among the surgical services. However, in most hospitals the so-called master surgery schedule tends to be the same for several years regardless of the changes in the surgical demand pattern and the raising numbers in the waiting list for surgeries. This work proposes a mathematical programming model for OR time allocation among surgical services with three objectives: to maximize the total number of allocated slots weighted by the preferences of the main stakeholders; to match supply and expected demand; and to level the workload of up- and downstream units. A comparison of the actual allocation of slots at the hospital under study with the one suggested by this approach is performed. Results show that the workforce is one of the major bottlenecks, suggesting a new distribution of the workforce among the services.

■ MB-32

Monday, 10:30-12:00 - G109

Algorithms for Sequencing and Assembly

Stream: OR in Life Sciences
Invited session
Chair: *Aleksandra Swiercz*

1 - Using GRASShopPER De Novo Assembler with Reduced Overlap Graph

Wojciech Frohmberg, Aleksandra Swiercz, Michal Kierzynka, Pawel Wojciechowski, Artur Laskowski, Jan Badura, Piotr Zurkowski, Marta Kasprzak, Jacek Blazewicz

Sequencing can be seen as a joint venture of computer science, biology, chemistry and medicine. Aim of the assembly problem, computational subproblem of sequencing, is to find shortest common superstrings built upon a given known set of sequences coming from intensive genetic material scan, called reads. The problem is very practical as at the current level of technology machines that provide reads, known as sequencers, are unable to determine entire sequence of a genome. Instead they provide relatively short genome fragments, though densely covering the genome.

There are two main strategies to solve the assembly problem, both originating from the sequencing by hybridization method: Overlap-Layout-Consensus (OLC) and Decomposition graphs (DG). Advantage of the former is quality of its results as well as resistance to errors in input data. On the other hand the latter strategy is seen as a far more efficient and, with preprocessing phase, providing acceptable results.

Last decade brought a lot of DG-based approaches solving assembly problem, but very few OLC assemblers able to deal with its bigger instances. Reason behind developing GRASShopPER was to prove that OLC strategy can work efficiently enough to assemble medium sized genomes. The talk is to show newest computational experiments suggesting that in case of some datasets we can reduce overlap graphs and improve GRASShopPER efficiency without a loss on results quality.

2 - De Novo Assembler. Novel Overlap Graph Construction

Artur Laskowski, Aleksandra Swiercz, Wojciech Frohmberg, Jan Badura, Pawel Wojciechowski, Marta Kasprzak, Jacek Blazewicz

Next generation sequencers produce billions of short DNA sequences which are then processed by assemblers to reconstruct the DNA strand. Assembling is an NP-complete problem due to the erroneous nature of reads provided by sequencers. In order to recreate the original strands, algorithms use graph representations of reads alignments. Graphs are later traversed in order to find paths maximizing total overlap between neighbouring reads. However, to obtain an alignment graph with satisfactory density, various steps need to be performed first. Most notably, we limit the number of alignments with use of k-mer hashing. We align the corresponding pairs of reads using a semi-global variant of the Needleman-Wunsch algorithm, which finds optimal alignments. Since it is computationally demanding and easily parallelizable we use a very efficient GPU implementation. The method produces an alignment score and a shift value for each pair of examined reads. If overlaps are sufficiently long and the number of alignment errors is below a given threshold arcs are created. Additionally, we implemented several further steps such as the creation of the smallest lexicographical index, which results in a denser graph. The traversing scheme is the final step of the algorithm. This step processes the previously generated graph and produces strands via analyzing reads and arcs that connect them to each other.

3 - Classifying Sequencing Data Using Linear Programming

María J. Nueda, Mariola D. Molina Vila, Carmen Gandia Tortosa

Classification methods have become in one of the main topics in the modern data analysis. The high number of variables available and specific types of distributional assumptions are challenging topics that scientists try to address with approaches as bagging, boosting or developing new statistical methods. We address the classification problem formulating an optimization problem, that looks for a hyperplane, H, which separates two groups. If such hyperplane does not exist, H will be found by minimizing the sum of all the possible infeasibilities. It results in a convex optimization problem for which we find an equivalent linear programming problem that is solvable by applying the Karush, Kuhn and Tucker conditions. We study the benefits of the method in the transcriptomics field. The use of RNA-seq for transcriptome profiling as a replacement for microarrays has triggered the development of statistical methods to properly deal with the properties of these types of count-based data. For classification purposes, methods based on gaussian distribution, as linear discriminant analysis, may not be appropriate for count data. Some authors propose methods to classify RNA-Seq samples based on the Poisson distribution or de Negative Binomial distribution. We show the results of the application of the method to real and simulated RNA-seq data, and we compare them with other classification methods for RNA-Seq.

4 - Simulation of RNA Sequence Evolution in the RNA World

Jarosław Synak, Agnieszka Rybarczyk, Jacek Blazewicz

Biology has gone a long way since its foundations: scientists throughout the centuries classified many species of plants and animals, various mechanisms in living cells were recognized and explained, simultaneously multiple gene mapping and manipulation techniques have been developed. Despite of this huge advancement in the field, there are still many questions which remain without an answer and the origin of life is one of them. One of the most popular hypotheses trying to explain how this actually happened is RNA World. According to it, in the beginning there were short RNA molecules which had formed spontaneously and some of them could catalyse the replication of other RNAs. This system, according to the hypothesis, was able to preserve information and eventually evolve into something much more sophisticated - modern day cells. Our goal was to use the tools provided by computer science and test the stability of such system against various initial conditions. Our model, which was used for this purpose, was initially designed as an extension of RP (replicase-parasite) model. We introduced some further improvements and added more complex chemical rules, which in our opinion, can make the simulation more biologically accurate and bring it closer to the reality.

■ MB-33

Monday, 10:30-12:00 - Q005

Modelling and Optimisation in Industrial Organisation I

Stream: Mathematical Modelling

Invited session

Chair: *Felipe Maldonado*

1 - Bounding the Value of Observability in a Dynamic Pricing Problem

Dana Pizarro, José Correa, Gustavo Vulcano

Research on dynamic pricing has been growing during the last four decades due to its use in practice by a variety of companies as well as the several model variants that can be considered. In this work, we consider the particular pricing problem where a firm wants to sell one item to a single buyer along an infinite time horizon in order to maximize her expected revenue. The firms pre-commits to the price function and the buyer, who has private value for the item and arrives according to some distribution, purchases at the time when his utility is maximized. We define the Value of Observability as the ratio between the expected revenue if the seller fix the pricing policy when she observes the buyer arrival-observable case- and the expected revenue if she fixes it at the beginning of the selling horizon- unobservable case. We prove that in a very general setting, the Value of Observability is at most roughly 3.591, which means that the seller's expected revenue in the observable case can not be more than 3.591 times the seller's expected revenue in the unobservable case. Even more, if we suppose that the buyer's valuation is distributed according to some distribution with monotone hazard rate, the bound is improved to e.

2 - Deep learning for portfolio risk and financial economics: Investigating trend change predictability through lagged correlations
Ben Moews, J. Michael Herrmann, Gbenga Ibikunle

The prediction of trend changes in noise-laden complex systems with large numbers of time series is a problem with a wide array of applications for real-world phenomena, with one notoriously difficult to predict example being the case of stock markets. We tackle the prediction of directional trend changes through interlaced lagged correlations between such time series, excluding any information about the respective target series from the model inputs to obtain trend change predictions driven by such time-delayed correlations. For this purpose, we make use of deep neural networks employing step-wise regressions with exponential smoothing in the preprocessing stage, with regression slopes being used as trend strength indicators. We apply this approach to recent stock market data over a five-year interval as an example of a complex system heavily influenced by noise in the form of externally arising new information, extend our analysis to the models' behavior in financial crisis scenarios, and investigate the complexity of the problem with bottleneck layers. Our results, which account for the need for rigorous statistical validation, showcase the viability of this approach, with state-of-the-art accuracies and implications for debates in financial economics.

3 - Multiagent learning for a multiplayer N-armed bandit machine with applications to congestion games
Sam O'Neill, Ovidiu Bagdasar, Stuart Berry

The classic N-armed bandit problem [Berry/Fristedt 1985] is widely used as an example in the area of reinforcement learning to demonstrate the requirement for an agent to balance its strategy between exploration and exploitation. The agent plays a fixed number of rounds, each round pulling a single lever and receiving an associated expected (mean) reward. The objective is for the agent to play a strategy which maximises the expected return after completion of the rounds. In the absence of prior knowledge of the expected returns of each lever, the agent must maintain estimates of these rewards, balancing the need for generating better estimates (exploration) and utilising current estimates (exploitation). One can view this as a one state Markov Decision Process, with the agent returning back to the start state after receiving the reward for the round. Many variants of this problem, such as the binary, Bernoulli and restless N-armed bandit machine, have been studied and practical applications include adaptive routing, portfolio design and clinical trials. This study presents a multiagent variant of the classic problem in which simultaneous game theory concepts, such as greed and fear, are interrogated to understand an agent's motivation for co-operation. It will also explore the effectiveness and applicability of known approaches and illustrate how this variant can be applied to network congestion games [Rosenthal 1973] such as the classic Traffic Assignment Problem [TAP].

4 - Compete or collaborate: pricing strategies under a multinomial logit model with non-linear network effects
Felipe Maldonado, Gerardo Berbeglia, Pascal Van Hentenryck

We consider a Multinomial logit model with network effects over the consumers' decisions. We study sellers' pricing strategies, where the purchasing decisions are affected by products' qualities, prices and past consumption.

Consumers can buy the product that maximises their expected utility or select a no purchase option. Unlike most of the related research, we consider network effects on the no purchase option, capturing in that way, the effect of consumers buying similar products somewhere else.

In our model, the network effects represent market interactions where consumers see a score function of the past consumption. Since the probability of choosing the available products dynamically changes over time, we use stochastic approximations techniques to prove that such probability converges almost surely to a stationary distribution, that represents the market share of each product in the long run.

We model the sellers' expected revenues based on the asymptotic market share distribution and the displayed prices. We first study the case where sellers collaborate, adopting a monopolistic pricing strategy to maximise the overall expected revenue, which turns out to be increasing in the strength of the network effects. We then study the case where the sellers compete, inducing a price competition game that has a unique pure Nash Equilibrium. We finally compare experimentally and analytically both cases, incorporating into the analysis, the consumers' perspective.

■ MB-34
Monday, 10:30-12:00 - Q006

Rolling stock

Stream: Public Transportation II
Invited session
Chair: *Anita Schöbel*
Chair: *Alexander Schiewe*

1 - An Hypergraph Model for the Rolling Stock Rotation Planning and Train Selection
Mohamed Benkirane, Francois Clautiaux, Boris Detienne, Jean Damay

The subject of this work is an integrated optimization approach for timetabling and rolling stock rotation planning in the context of passenger railway traffic. Our approach is based on an hypergraph based integer programming model, which can handle trains composed by multiple heterogeneous self-powered railcars. The method aims at producing a timetable and solving the rolling stock problem given a set of possible passenger trips, a service requirement and a fleet of self-powered railcars. The produced timetable optimizes the production cost and especially the use of railcars. To solve our optimization problem, we use a minimum cost flow problem in a time/space/configuration hypergraph network. These models are used to handle effectively constraints related to coupling and decoupling railcars. To reduce the size of the generated model, we propose a reduced-cost fixing method based on a surrogate relaxation of the flow constraints. This relaxation allows to produce a relaxed model with a similar structure, but significantly less variables and constraints. We are able to produce both lower and upper bounds for the initial problem. These bounds allow to apply implicitly reduced-cost fixing techniques to the initial model. The obtained reduced version of the initial model is then solved by an MIP solver. We present some results based on several French regional railway traffic case studies to show that our methods scales to real-life problems.

2 - Effect of standardization on rake utilization in rolling stock
Swapnesh Subramonian, Narayan Rangaraj

Efficient circulation of rolling stock is important in any railway system and the time table made by the operator should be in line with this objective. In this paper, the effect of rake standardization on rake utilization is studied, in the context of passenger railway transportation. In a set of standardized rakes, the composition of rakes remains the same. Identification of standardized composition, based on demand analysis and operational constraints is crucial. Prior to mathematical modeling, preliminary analysis has been done, which indicated the possibility of an increase in rake utilization by using rakes having standardized composition. The minimum number of rakes required, for a given set of services is obtained using an integer programming model. The model is based on graph coloring framework, which is a well-known problem in combinatorial optimization. The analysis is done for a subset of trips originating from a busy terminus in Indian Railways. It is found that these trips, as per the given time table can be run with a smaller number of standardized rakes. The trade-off between the costs and benefits of standardization is analyzed. The possibility of minor modifications in the time table for better results is also explored.

3 - Biased Randomised Variable Neighbourhood Search for Railway scheduling in the presence of uncertainties
Nattapol Paisarnvirosrak, Djamila Ouelhadj, Banafsheh Khosravi

Railway scheduling and rescheduling play a central role in day-to-day railway operations. Trains on a railway network are scheduled and controlled according to a timetable. However, trains are not always run based on the proposed timetable because there might be some unpredictable disruptions due to excessive dwell times at stations, infrastructure and/or train faults, and the late arrival of crew. In this study, we aim to minimise the total delay of trains while considering passenger safety and regulation principles including running times, headway and signalling system constraints. The problem is formulated as a Modified Blocking Job Shop Scheduling (MBJSS) model, which is adapted from the classical job shop scheduling model. We propose the Biased Randomised Variable Neighbourhood Search (BRVNS) to solve the railway re-scheduling problem in the presence of delays caused by travelling/dwell time delay and late departure time. The BRVNS algorithm starts with biased randomised heuristic to generate an initial solution then VNS is used to improve the solution. To evaluate the performance of the proposed optimisation model and BRVNS, we have conducted computational experiments using a real-world case study from the railway network in Thailand. The results show that the BRVNS algorithm has outperformed the solution used by the railway network in Thailand and it could improve the efficiency of Thailand railway management by decreasing the total train delays.

4 - OR in shunt planning
Joel van 't Wout

The final planning phase for a railway operator is the shunt planning. This involves the processes within the local station area, mainly choosing a parking track for the trains and finding routes between the station and the shunting yard. OR models for shunt planning can be of great help to the planners of Netherlands Railways, because of limited parking and routing capacity in the Dutch railway network. Moreover, NS would like to make the shunt plans as late as possible, generating time pressure for the planners. We will present a model that solves the problem of matching, parking and routing rolling stock. In our approach we split the problem in subproblems for which we formulate a MIP. Recently we added the planning of service activities like cleaning and technical checks. We incorporate these service activities in our model in a heuristic way.

■ MB-35

Monday, 10:30-12:00 - Q009

Game Theory, Solutions and Structures I

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Encarnación Algaba*

1 - On egalitarian values for TU-games with a priori unions
Juan Carlos Gonçalves, Ignacio García-Jurado, Julian Costa, José María Alonso-Meijide

In many economic situations, several agents cooperate to generate benefits. Cooperative game theory studies procedures to allocate the resulting benefits among the cooperating agents. One of these allocating procedures is the egalitarian value, where the benefits be shared equitably. In this work we modify the equal division value and the equal surplus division value for games with a priori unions. Being a game with a priori unions one where there exists a partition of the set of players, whose classes are called unions, that is interpreted as an a priori coalition structure that conditions the negotiation among the players and modifies the fair outcome of the negotiation.

2 - Coalitional multinomial probabilistic values. A political example
María Albina Puente, Francesc Carreras

Coalitional multinomial values were introduced by Carreras and Puente in 2015. Each one of them depends on n parameters, which are interpreted as players' individual tendencies to form coalitions, so these values are designed to take into account players' attitudes with regard to cooperation. They combine the Shapley value and the corresponding multinomial probabilistic value (Freixas and Puente, 2002). They first apply this latter value to the quotient game and obtain a payoff for each union; next, they apply within each union the Shapley value to a reduced game, played in the union, for sharing that payoff efficiently. This looks highly interesting for a voting setup since, once an alliance is formed -and, especially, if it supports a coalition government-, cabinet ministries, parliamentary and institutional positions, budget management and other political responsibilities have to be distributed among the members of the coalition efficiently, whence in a way as close as possible to the one suggested by the Shapley value. This family lies in the class of probabilistic values, widely generalizes the symmetric coalitional binomial semivalues (Carreras and Puente, 2012) and provides a promising framework for applications. In this work a new axiomatic characterization of each coalitional multinomial value with positive profile is obtained by just replacing the property of symmetry within unions with the property of balanced contributions within unions.

3 - The canonical extension of the Shapley value for cooperative games with externalities
André Casajus, Frank Huettner

We identify one extension of the Shapley value to games with externalities from the literature (Macho-Stadler, Pérez-Castrillo, Wettstein: J Econ Theor, 135, 2007, 339–356) as the canonical one. Other attempts for extensions via generalizations of unanimity games, null players, monotonicity properties, or average games lead into ambiguities and technical problems. Our extension is based (i) on the potential approach to solutions for games with externalities (Dutta, Ehlers, Kar: J Econ Theor, 145, 2010, 2380–2411) and (ii) on a natural extension of the potential of the Shapley value (Hart, Mas-Colell: Econometrica, 57, 1989, 589–614) to games with externalities and a corresponding restriction operator both based on the interpretation of the potential as the worth of a random partition (Casajus: Econ Lett, 126 (2), 2014, 164–166).

4 - Harsanyi power solutions on the set of winning coalitions of a voting game
Encarnación Algaba, Sylvain Béal, Eric Rémila, Philippe Solal

This paper deals with Harsanyi power solutions for cooperative games in which partial cooperation is based on specific union stable systems given by the winning coalitions derived from a voting game. This framework allows for analyzing new and real situations in which there exists a feedback between the economic influence of each coalition of agents and its political power. We provide an axiomatic characterization of the Harsanyi power solutions on the subclass of union stable systems arisen from the winning coalitions from a voting game when the influence is determined by a power index. In particular, we establish comparable axiomatizations, in this context, when considering the Shapley-Shubik power index, the Banzhaf index and the Equal division power index which reduces to the Myerson value on union stable systems. Finally, a new characterization for the Harsanyi power solutions on the whole class of union stable systems is provided and, as a consequence, a characterization of the Myerson value is obtained when the equal power measure is considered.

■ MB-36

Monday, 10:30-12:00 - Q010

Inventory Routing I

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Luca Bertazzi*
Chair: *Demetrio Laganà*
Chair: *Philippe Lacomme*

1 - Testing the importance of the planning horizon when solving inventory routing problems.
Mohamed Ben Ahmed, Arild Hoff, Lars Magnus Hvattum

The inventory routing problem (IRP) is a well-studied supply chain problem that involves the coordination and the integration of two logistic problems: inventory management vehicle routing. More specifically, the problem requires computing the quantities of goods to be delivered for each customer during a specified time horizon, as well as associated vehicle routes. In practice, when building IRP models, the time horizon is segmented into a sequence of finite planning periods. A salient prerequisite for effectively solving the IRP is thus to determine the proper length of these periods. Whereas short planning periods should produce more tractable variants of the IRP, they may fail to derive cost-effective solutions. The reason is that end-of-horizon effects are normally not explicitly considered, and the plans produced may imply that final inventories of customers are almost empty. This may again lead to increased costs in later planning steps. The scope of this work is to investigate for a set of benchmark instances the impact of both planning periods' length and the inventories terminal conditions and determine a trade-off between cost and tractability. We resort to a matheuristic solution approach, which combines the assets of mathematical programming and a tabu search metaheuristic, to tentatively solve the considered problem.

2 - Improved branch-and-cut algorithm for the inventory routing problem
Jørgen Skålnes, Magnus Stålhane, Henrik Andersson, Guy Desaulniers

We propose an exact solution method to the Inventory Routing Problem, where each customer has an inventory with a maximum holding capacity and a periodic demand. The decision maker has to make sure the customers have enough products in their inventories to satisfy demand in each time period of the planning horizon. Thus, the decision maker has to decide which customers to serve in which time periods, how much to deliver of a product once a customer is visited and how to route the fleet of vehicles in order to minimize transportation cost and inventory holding cost. We propose an improved branch-and-cut algorithm combining the current state-of-the-art valid inequalities with new families of valid inequalities using the concept of delivery patterns. Preliminary results show that the new algorithm increases the lower bound considerably and on average reduces the solution times. A full computational study on how the different valid inequalities impact the lower bounds and solution times will be presented.

3 - A Two Commodity-Based Branch-and-Cut Algorithm for the Inventory Routing Problem
Eleftherios Manousakis, Panagiotis Repoussis, Emmanouil Zachariadis, Christos Tarantilis

We consider the Inventory Routing Problem (IRP) which integrates the routing and the inventory management decision across a time period. A supplier applying the Vendor Managed Inventory (VMI) system is responsible for replenishing geographically dispersed customers using a limited fleet of capacitated vehicles over a discrete time horizon according to Maximum Level (ML) inventory replenishment policy. The objective is to decide the timing, the quantities and the routes of re-supplying customers in order to minimize the conflicting distribution costs and the inventory costs simultaneously. We present a new effective two commodity flow-based formulation for the IRP, effectively reducing the size of the Mixed Integer Linear Programming problems for larger instances. Two new case specific families of valid inequalities are presented. We develop a fast Tabu Search (TS) algorithm for the relaxed formulation of IRP with Order-Up-to level (OU) instead of ML policy. The TS is used to provide high-quality initial solutions to a novel branch-and-cut scheme. We experiment with different heuristic, exact and local search separation routines for separating families of cuts in the branch-and-cut framework. Preliminary results suggest new optimal solutions for well-known literature instances. Additionally, new upper and lower bounds are reported for harder instances.

4 - Efficient strategies in Constraint Programming for Inventory Routing Problems
Philippe Lacomme, Axel Delsol, Christophe Duhamel, Helen Toussaint

Modeling a problem using a Constraint Programming (CP) approach means defining variables, their domains, and linking them using constraints. An efficient CP model should take advantages of the global constraints and the enumeration strategy to improve the propagation. The propagation uses the constraints to explore the search space while exploiting the problem characteristics. CP can rapidly find feasible solutions to combinatorial optimization problems, assuming we can use the problem properties to drive the exploration. We present here a CP approach to solve the Multi-vehicle Inventory Routing Problem and study both the propagation and the enumeration strategy. In the MIRP, a supplier has a fleet of homogeneous vehicles and manages the inventory level of its customers over a time horizon. One must design routes such that customers' demands are satisfied, and the sum of the transportation and inventory costs is minimized. We build an initial model to solve the MIRP. Then we add redundant constraints to improve the propagation. Finally, we propose 3 enumerations strategies: period based, customer based and a hybrid one. Experiments on the benchmarks from (Archetti et al., 2007-2012) shows that each modification, especially the enumeration strategies, significantly reduce the solving process.

■ MB-37

Monday, 10:30-12:00 - Q011

Scheduling Practice

Stream: Scheduling with Resource Constraints
Invited session
Chair: *Yongtu Liang*
Chair: *Elina Rönnberg*

1 - Scheduling optimization of water injection systems in oilfields
Bohong Wang, Yongtu Liang, Jing Liu

Water injection is a main development method to enhance oil recovery. With the continuous development of oilfields, the demand for water injection is growing. Water scheduling optimization is important to ensure the demand of water injection wells can be satisfied with the minimum operating cost. Generally, water injection rate of each well changes according to the development requirements. Therefore, a method should be proposed to find an economic way to schedule water sources to wells. Water is usually started from central process facilities (CPFs) and transported through pipelines or trucks. Depots are located in CPFs, wells, and some junction points of pipelines. To minimize the operating cost, an MILP model that takes inventory, transport capacity and pipeline operation as constraints is developed. This model is applied to a real case of a water injection system in a carbonate oilfield. The network of this oilfield is in the branched form, it has two water source and 10 injection wells. The scheduling plan of water including the operational plan of the pipeline network and the dispatch plan of trucks can be solved. A model that considers the scheduling of water injection systems in oilfields with both pipelines and trucks transport modes is proposed. The model can also be used in other oilfields to reduce the operating cost and guarantee the water injection demand.

2 - Energy Aware Scheduling of a Material Handling Robot in an m-Machine Robotic Cell
Rabia Taspinar, Hakan Gultekin, Sinan Gürel

Due to the policies and regulations for sustainability, manufacturers started to attempt to determine the trade-off between the time-related and the energy-related objectives. To handle this issue, we consider a bi-criteria robotic cell scheduling problem to identify the trade-off between the cycle time and robot's total energy consumption in a robotic cell consisting of m serial machines and a material handling robot. This robot loads/unloads the machines and transfers the parts between the machines. In this study, we focused on the efficient planning of the sequence of these robot movements and the corresponding speeds. We developed a Mixed Integer Nonlinear Programming (MINLP) formulation, and a more efficient Mixed Integer Second-Order Cone Programming (MISOCP) formulation, respectively. In these formulations, the energy consumption function is assumed to be convex and nonlinear with respect to the robot speed for each move, and the speeds are considered as decision variables. We utilize the epsilon-constraint approach to handle this problem, and the cycle time objective is considered as a constraint. Because of the excessive solution time of these formulations, we also developed a heuristic algorithm. The performance of this algorithm is tested by a computational study. Our results indicate that robot speed control can reduce the energy consumption significantly for the same cycle time while providing a set of pareto-efficient solutions for the decision maker.

3 - Hybrid Flow Shop Design And Scheduling in an Aerospace Industry
Yiğitalp Özmen, Sedef Meral

We address the design and production scheduling problems in the manufacturing of fuselage skin in an aerospace industry. In the first phase, by means of discrete event simulation(DES), the current job shop environment is redesigned as a hybrid flow shop in an attempt to improve the output quality, lessen materials handling and shorten the production lead time. In the second phase, the production scheduling problem of the shop is formulated as a hybrid flow shop(HFS) scheduling problem and modelled as a mixed integer linear programming(MILP) model and a constraint programming(CP) model as well, which are solved for the optimal or near optimal solution by using CPLEX. Due to NP-hardness property of the HFS problem, with MILP, only a near optimal solution can be obtained for real data. Hence, we resort to heuristic methods such as: dispatching rules using LEKIN scheduling software, and Johnson, Palmer, CDS and NEH algorithms. We also develop a hybrid method that is a random search combined with global lower bound, ensuring not to be stuck in local optima. Each solution method's best schedule is simulated by the DES model and the makespan of each schedule is thus obtained. It is observed that our proposed hybrid method outperforms the other solution methods in real data. Since the deviations from the lower bounds turn out to be acceptable for medium, real and large instances, our hybrid method seems inspiring for further studies.

4 - Combining constraint generation and adaptive large neighbourhood search to solve an avionic scheduling problem
Emil Karlsson, Elina Rönnberg, Andreas Stenberg, Hannes Uppman

Large-scale scheduling problems occur in the development of electronic systems in aircraft, called avionic systems. This talk addresses one avionic scheduling problem where the goal is to determine if an instance of a multiprocessor system can be scheduled with respect to multiple time windows, precedence relations, and additional technical constraints. We present a matheuristic that extends a constraint generation procedure with an adaptive large neighbourhood search to solve instances with up to 50 000 tasks.

The constraint generation procedure utilises that tasks have multiple time windows. A relaxed problem is formed where the sequencing constraints are omitted and the tasks are only to be assigned to time windows. One such assignment of tasks is then evaluated in a subproblem from which sequencing constraints are generated if necessary.

The adaptive large neighbourhood search solves the relaxed problem in the constraint generation procedure by exploring a series of mixed integer programming models as neighbourhoods. The neighbourhoods utilise the underlying problem structure to select tasks that change time windows to improve the current solution. The performance of the matheuristic is evaluated for two categories of instances, developed in collaboration with our industrial partner Saab.

■ MB-38

Monday, 10:30-12:00 - Q012

Urban and Territorial Planning in MCDA 1

Stream: Multiple Criteria Decision Aid
Invited session
Chair: *Isabella Lami*
Chair: *Francesca Abastante*
Chair: *Marta Bottero*

1 - "Sense" and "essence" as contents of the multidimensional decision making processes in the landscape units' recovery
Salvatore Giuffrida, Maria Rosa Trovato

The landscape of the Sicilian mountainous inland is marked by old towns once controlling large agricultural land areas, and conferring them a recognisable landscape significance. This societal, economic and urban shape, is nowadays a "legacy interrupted" due to the radical transformation of the economic relationships between the traditional societal economic classes, as well as to the technological progress, which eroded the link between natural structures and cultural superstructures. Nowadays, the landscape values still to be found in these territories should be assumed as the raw material for landscape policies trying to invert the impairment of such unity, but specific decision making tools need to be developed and performed to support these policies. This contribution try to identify some fundamentals of the notion of landscape, able to overcome the superficial approach based on the mere individual and hedonic perception, on the side of "consumers", and on the judgement of technicians, according to the constructivist approach, on the side of the DM. These fundamentals concern two concepts, "sense" and "essence", respectively coming from the structuralist and the phenomenological approach, and related to the relationship between "truth" and "value".Accordingly, a multidimensional decision making pattern is outlined combining the phenomenologic concepts of "immanent perception", and the semiotic concept of "semantic chain"

2 - Evaluation of the resilience of complex territorial systems by using MCDA: an application to the Douro Valley (Portugal)
Vanessa Assumma, Marta Bottero, Júlia Maria Lourenço, Roberto Monaco, Daniel Souto Rodrigues, Ana Jacinta Soares

The present work focuses on the development of an integrated evaluation framework with the aim to assess the resilience of an environmental system. This framework analyses the environmental system by employing a set of territorial resilience indicators in the framework of a Multicriteria Decision Analysis (MCDA), and by integrating a Lotka Volterra mathematical model of cooperative type. The system of territorial resilience indicators is able to identify the most valuable and the most critical areas that need intervention in terms of enhancement and conservation. The mathematical model is a Network Environment Model (NEM) that aims to simulate future territorial scenarios when the connectivity between the landscape units under investigation is taken into account. This integrated evaluation framework is here applied to one of the most important European wine regions located in Northern Portugal: the Douro Valley. Such framework may be considered a useful support for technicians and decision-makers in the field of regional development and planning to interpret complex territorial dynamics and so defining more sustainable territorial policies and actions.

3 - A Spatial multiple criteria decision aiding approach to enhance cultural heritage in fragile vulnerable contexts
Catherine Dezio, Marta DellOvo, Maria Cristina Giambruno, Paolo Pileri, Alessandra Oppio

The introduction of the concept of sustainable development in the field of cultural heritage preservation has stressed the importance of a holistic approach. Achieving a balance among cultural significance retention and economic development is a challenging policy and design territorial issue, even more in fragile and vulnerable contexts with limited resources, low return expectations and a huge tangible and intagible cultural heritage. Given such a complexity, decisions require to be based on robust methodolgies in order to address choices toward a balanced trade-off between conflictual goals. In this perspective, Spatial Multicriteria Decision Aiding methodologies can support decision makers along all the steps of the process, moving from intelligence to design and, finally, to choice phase. Within this approach, we have focused on the intelligence phase with the purpose of defining a multidimensional analytical framework aimed at mapping cultural heritage with a special attention to the territorial features. The proposed framework points out the challenge of structuring a decision problem related to cultural heritage widespread along slow mobility routes. The pilot case study is represented by an on-going cycle route that crosses Northern Italy transversely. The results obtained are value maps that provide recommendations for the definition of potential regeneration strategies to be transferred to similar territorial contexts.

4 - Multiple criteria decision analysis to compare hypotheses of adaptive reuse for an iconic historical building
Beatrice Mecca, Isabella Lami, Francesca Abastante, Salvatore Corrente, Salvatore Greco

The paper analyses six hypotheses of adaptive reuse of an iconic historical building in Italy (called "Borsa Valori") to identify the preferred alternative of requalification, by using the conjunction of Multiple Criteria Hierarchy Process (MCHP), ELECTRE III, imprecise SRF method and Stochastic Multicriteria Acceptability Analysis (SMAA) (Corrente et al. 2017). The MCHP takes into account the hierarchical structure of criteria on which the alternatives are evaluated; ELECTRE III, taking into account three types of interaction effects between criteria (strengthening, weakening and antagonistic effects), produces a partial ranking of the alternatives at hand; the imprecise SRF method permits to take into account uncertain preference information provided by the DM, while the SMAA methodology permits to provide robust recommendation, in terms of rankings and relations of preference, indifference and incomparability between the project alternatives, at each level of the hierarchy. The debate around the requalification of the "Borsa Valori", conducted in the last two years, has been huge for several reasons: the building is perceived as an historical "monument" by the citizens; it shows extraordinary architectural and typological values with a high reputation at the national level; it involves public and private interests. Despite simulated, the decision process has been conducted interfacing with experts involved in the real ongoing discussion.

■ MB-39

Monday, 10:30-12:00 - Q014

Resource constrained project scheduling

Stream: Project Management and Scheduling
Invited session
Chair: Norbert Trautmann
Chair: Jürgen Zimmermann

1 - A branch-and-bound procedure for the resource-constrained project scheduling problem with partially renewable resources and time windows
Kai Watermeyer, Jürgen Zimmermann

The resource-constrained project scheduling problem with partially renewable resources which is denoted by RCPSP/π has received relatively less attention by the research community to this day. For the RCPSP/π the capacity of each resource is given for an arbitrary subset of time periods of the planning horizon whereby each activity with a demand for this resource only consumes it if the activity is executed during these periods. The partially renewable resources make it for instance possible to model problems in the area of complex labor regulations. Our work focuses on the development of a branch-and-bound procedure for a generalization of the RCPSP/π which takes minimal and maximal time lags between pairs of activities into consideration. The new enumeration scheme makes use of the fact that the consumption of a resource by an activity is dependent on its start time. In each search node the earliest time-feasible schedule is determined by a modified label correcting algorithm where each activity is restricted to certain time points. If the calculated schedule is not resource-feasible, the resource conflict is reduced by excluding all start time points of an activity with the same resource consumption, so that the given resource conflict cannot occur in following search nodes. To improve the performance of the branch-and-bound procedure we develop an efficient destructive lower bound based on the relaxation of schedule dependent start time windows.

2 - An MILP formulation for the Multi-Mode Resource-Constrained Project Scheduling Problem MRCPSP
Norbert Trautmann, Mario Gnägi

We propose a novel MILP formulation for the MRCPSP based on variables representing the assignment of the project activities to individual resource units and the sequential relationships between activities that are assigned to at least one identical resource unit. The model exhibits advantageous performance for instances with long activity durations.

3 - Selecting mixed-integer programming formulations for resource-constrained project scheduling problems via machine learning
Andre Schnabel

The resource-constrained project scheduling problem (RCPSP) describes the task of finding the shortest feasible schedule for a given project. Several exact and heuristic solution algorithms as well as various mixed-integer programming (MIP) model formulations exist for this problem. The relative performance of these different solution approaches depends on the structural characteristics of the project instances. Furthermore, there is no single best solution approach that consistently dominates the other approaches on all instances.

Throughout this talk, the construction of a MIP model formulation selection tool for the RCPSP is documented. Generating the training data involves the identification of useful instance characteristics and running a portfolio of competitive model formulations on representative test sets. This data is then used as an input for different ML methods in order to build a classifier that predicts the best solution approach for a given instance. As two novel ML methods, we evaluated AutoML and Deep Learning and present the corresponding numerical results. The results show a high classification accuracy and a considerable performance impact in comparison to only using the single MIP formulation with the best performance on average.

4 - Solution Methods for the Resource-Constrained Multi-Project Scheduling Problem with Flexible Project Structures
Luise-Sophie Hoffmann, Carolin Kellenbrink

In flexible projects it is not fully known it advance, which jobs have to be executed. Hence, in addition to scheduling the jobs, in the resource-constrained project scheduling problem with a flexible project structure (RCPSP-PS) the project structure needs to be determined. In application fields such as the regeneration of complex capital goods, multiple projects use the same renewable and non-renewable resources.

Therefore, they have to be planned simultaneously. In this talk, the resource-constrained multi-project scheduling problem with flexible project structures (RCMPSP-PS) is presented. The objective of the RCMPSP-PS is to minimize the total penalties for delay. For the purpose of solving multiple flexible projects, different solution methods are considered. A comprehensive numerical study indicates the performance of these solution methods.

■ MB-40

Monday, 10:30-12:00 - Q015

OR in the Physical Internet - 2

Stream: OR in the Physical Internet
Invited session
Chair: Teresa Pereira

1 - Physical Internet in the Automotive Industry
Uday Venkatadri, Simranjeet Singh Chadha, Muhammed Ali Ulku, Ana Cristina Mora Sanchez

We look at the application of the Physical Internet (PI) in the Automotive Industry using the Mexican example. A case study for PI is built centered around a network comprising automotive plants, domestic Tier 1 suppliers, and ports through which parts are imported. The PI logistics system offers natural advantages for the automotive industry since smaller frequent consolidated shipments reduce inventory at the plants. This research looks at the trade-off between transportation and inventory costs for three networks: a traditional network involving milk runs from the suppliers (or ports) to the plants, a PI system with a PI-hub with directed shipments in to and from the hubs. An alternative PI system considers milk-run deliveries to the plants from the hubs, while the inbound transportation is direct.

2 - Flexible terminal assignments in intermodal container routing
Kris Braekers, Hilde Heggen, An Caris

This work focuses on intermodal rail transport. Logistics service providers offer door-to-door container transport by combining long-haul rail services between intermodal terminals with local drayage operations by truck for transporting containers between customer locations and terminals. Traditionally, containers are assigned to terminals and long-haul services before local drayage operations are planned. However, this may be sub-optimal. Emerging concepts such as synchromodality and the Physical Internet rely on the idea that containers are routed through an interconnected network of terminals depending on the network capacity, where customers are no longer concerned about the actual routes the containers follow. In this context, we propose a new integrated container routing problem in which drayage operations and long-haul rail services are planned simultaneously. As a result, terminal assignments are not predefined, but are flexible: the terminals and long-haul rail services to use depend on the current capacity availability and the opportunities to optimize local truck routes. To solve this combinatorial optimization problem, a meta-heuristic algorithm based on Large Neighborhood Search is proposed. Numerical experiments based on a real-life case are performed to show the advantage of using flexible terminal assignments in intermodal transport. Finally, it is demonstrated how the model may be applied to support tactical decisions on the intermodal service network.

3 - A Decision Support System to the last mile maritime container distribution problem in the context of the Physical Internet
Teresa Pereira, Manuel Lopes, Luis Ferreirinha

The constant and hasty development of economic globalization is increasing the complexity of transport networks and causing significate changes in cargo transport, prioritizing customer service over an effective and efficient low-cost distribution. Last mile transportation of containers is a process that can be optimized to bring benefits to stakeholders: shipping agents, freight forwarders, carriers, companies, ports and society. This paper proposes a Decision Support System (DSS) to optimize the last mile of maritime containers in the distribution chain in an integrated overview of Physical Internet. A three-stage algorithm is proposed. In the first stage, a multi-criteria model selects from the available fleet, the trucks with the best rankings. In the second stage a LP optimization model assigns the containers to the trucks, maximizing the number of transported containers. In the third stage a meta-heuristic solves a dynamic VRP. Ten random instances were computed to validate the algorithm. The developed DSS allows to allocate the closest empty trucks and give the respective quotes automatically, based on predefined criteria and the proposed algorithm. The result will lead to a better management of infrastructures, reduction of environmental footprint, increase customer' service level, reduction of empty kilometers, less cost and reduction of the receipt period and a more collaborative framework.

■ MB-41

Monday, 10:30-12:00 - Q013

Line planning and network design for public transport services

Stream: Public Transportation I
Invited session
Chair: Pieter Vansteenwegen

1 - Considering emissions in the network design and frequency setting problem with a heterogeneous fleet
Javier Duran Micco, Pieter Vansteenwegen

This work addresses a variant of the Transit Network Design and Frequency Setting Problem (TNDFSP). The TNDFSP usually considers only the passengers' and the operator's point of view. However, we show it is worthwhile to consider also the emissions already during this planning phase. A bi-objective memetic algorithm (MA) is proposed where both the total travel time and the CO2 emissions are minimized. The analysis considers a heterogeneous fleet, meaning that buses of different sizes and technologies can be assigned under a budget constraint. Numerical experiments show that the MA performs as well as state-of-the-art algorithms where CO2 emissions are not considered, obtaining very good solutions under reasonable computing times. Additionally, several experiments are performed to observe the effect of incorporating CO2 emissions and a heterogeneous fleet into the TNDFSP. It is shown that significant reductions in the emissions can be achieved while only slightly increasing the total travel time and maintaining the cost, compared to the solution aiming at minimizing travel time. In the tested instances, the emissions can be reduced around 30% by increasing the travel time only around 1.5%. Even in the scenario with a homogeneous fleet, emissions can be reduced around 8% increasing the travel time less than 1%. Those results clearly demonstrate the benefits of considering both the CO2 emissions and a heterogeneous fleet during the design stage of public transport systems.

2 - A comparison of unscheduled fixed-route minibus-taxis and pooled ride-hailing in a model of Cape Town
Gregor Leich, Kai Nagel

Minibuses operating on fixed routes, but without a schedule, constitute informal public transit systems often found in developing countries. In Cape Town, South Africa, the so-called minibus-taxis proceed along a fixed route picking up and dropping off passengers along the way (there are no fixed stops).

In recent years transportation network companies like Uber started to offer dynamic ride-hailing with passenger pooling. These services are not restricted to fixed routes. Instead the passenger can specify pickup time and location as well as dropoff location. This potentially allows for a better adaptation to the passengers' needs while still bundling multiple passenger trips to be served by the same vehicle at the same time.

A simulation study for Cape Town using a microscopic simulation model (MATSim) investigates expected changes in travel time and operation cost for replacing today's minibus-taxis with a pooled ride-hailing service. Our results indicate that, when using the same number of vehicles and the same capacity per vehicle, the ride-hailing fleet is very overloaded, so wait and in-vehicle times increase significantly. This suggests that minibus-taxis on fixed routes are more efficient in bundling passengers with different origins and destinations.

3 - Optimal fleet allocation for skip-stop strategies in rail transit lines

Ramón Piedra de la Cuadra, Juan A. Mesa, Francisco A. Ortega Riejos, Miguel Angel Pozo

The Skip-Stop operation consists of offering shorter travel times to a larger number of passengers by selecting a group of low-activity stations, where trains do not stop to pick up or let off passengers. In railway systems, a skip-stop mechanism may be used to reduce travel time of particular trains by not stopping (skipping) at less densely populated stations. The travel time between stations consists of five components, usually identified as phases of acceleration, constant speed, inertia, braking and downtime. The operation of omitting stops reduces the travel time for the users within the vehicle and increases the speed of operation in the provision of new transit services. But, other users will experience, if this strategy were applied, a longer time of waiting, accessing, exiting and, possibly, transferring. The deterministic approach of this strategy pattern for a one-way single track consists of classifying stations along a line into three groups: A, B and AB. The trains in line A stop at the A and AB stations, while the trains belonging to line B stop at the B and AB stations. We propose to determine a Skip-Stop strategy through a two-phase methodology. In the first, we find the optimal strategy of skipping stops for a given train fleet and, in the second phase, we will develop the concept of proximity between configurations of train itineraries and, in accordance with the Hall method, design a Math-heuristic that optimizes the Skip-Stop strategy.

4 - A Grid based evaluation technique for passenger routing in bus line planning.

Evert Vermeir, Pieter Vansteenwegen

In bus line planning, a public transport company needs to decide which possible bus stops will be served, in what order. This is a computationally heavy procedure. Especially the calculations of the passenger routing are very time consuming. Every time a change to the public transport network is considered, the passenger routing has to be recalculated entirely. To make it possible to construct a high quality line plan for large networks in a reasonable amount of time, more efficient evaluation techniques are necessary. This will also be needed if you want to integrate other planning stages, like timetabling, into the line planning procedure. We developed a Grid based approach to evaluate the passenger routing locally. We observed that a passenger is more likely to be impacted by a change if he is already travelling close to said change. When evaluating the impact of a change, a part of the network is cut out. The method then assumes that all routes that travel through this cut, will still enter and leave this area at the same location, even after a change has been made to the network. Only the routing inside the cut will change. The computational effort required to recalculate the passenger routing in such a cut-out network is quasi constant with respect to the problem size and only depends on the size of the cut. This makes the method scale nicely with overall problem size. This research was funded by FWO (Research Foundation Flanders; project G.0853.16N).

■ MB-42

Monday, 10:30-12:00 - Q113

Transportation network vulnerability I

Stream: Transportation
Invited session
Chair: Kash Barker

1 - Response plan in disaster management considering the population behavior in evacuation in a flood

Pamela P. Alvarez, Francisca Carrera, Andrés Bronfman

Chile is a country highly exposed to the occurrence of natural events, which can cause disasters that significantly affect the population and the environment. Proper preparation, with response plans for these events, is crucial to save lives, reduce the suffering of the population and contribute with the resilience. To approach the problem, a methodology is proposed that allows to establish actions of preparation and response to flood disasters due to the occurrence of an alluvium. The problem of (i) location of shelters and warehouses with capacity restrictions is addressed, (ii) allocation of particular population groups to shelters, (iii) allocation of warehouses to demand points, and (iv) pre-positioning of multiproduct stock in warehouses. A response plan to a flood disaster is obtained as a result. To apply this methodology also is necessary to include information on the behavior of the population in evacuation. It is important to know the number of people that decide evacuate, and the percentage of them who go to the enabled shelters. The methodology was implemented in the city of Copiapó, Chile; considering the number of evacuees through a survey study in which the main incident factors for evacuation decision making are determined.

2 - Integrating network vulnerability assessment, resource allocation strategies and design operations: A unified approach for Critical Information Infrastructure Protection

Annunziata Esposito Amideo, Luca Faramondi, Maria Paola Scaparra, Roberto Setola

Critical Infrastructures (CI) are those physical and virtual assets, networks and systems whose disruption can have a debilitating impact on vital societal functions, thus affecting a nation's security, economy, and public health and safety. This work focuses on a specific category of CI, namely the Critical Information Infrastructures (CII), such as backbone networks that ensure connectivity among distributed systems in order to allow remote monitoring, access control, data sharing as well as payment services. It is clear that CII are key elements in production and service systems given that even a local failure at the single CII level (e.g., shut down servers, interrupted cable connections, etc.) may prompt far-reaching adverse effects on the CI relying on it. Information infrastructure security can be improved through the optimal allocation of protective resources among system components. This work presents a novel linear bi-level program for the protection of CII, integrating network survivability assessment, resource allocation strategies and design operations, namely the Critical Node Detection Problem with Fortification (CNDPF). The CNDPF is solved through a decomposition method based on Super Valid Inequalities (SVI) and through a Greedy Constructive and Local Search (GCLS) heuristic. Computational results are reported for real communication networks and for different levels of both disaster magnitude and protection resources.

3 - Planning of replacement services in case of metro disruptions

Alexander Kiefer, Karl Doerner, Michael Schilde

The presented work deals with severe metro disruptions and providing alternative routes for the affected passengers. In some cases passengers may resort to other already existing lines, including tram and bus lines, if they operate in close proximity to the disruption. In other cases replacement services with shuttle buses need to be established. Since usually only very few vehicles and drivers are on standby at depots, buses from existing lines have to be relocated to the newly established lines. Hence, the headways of the existing lines have to be adjusted. The lexicographic objective first minimizes the number of unserved customers. Second, the number of established shuttle lines should be minimized, as each shuttle line causes disruptions by itself, i.e., by personal rescheduling, headway adjustments, etc. Finally, the travel times of the affected passengers should be minimized. A mixed integer programming model has been developed to construct the shuttle lines and adjust the headways of all lines. The model is tested on instances of the Viennese public transport network and is able to provide optimal solutions within hours for instances where only smaller regions are considered. These solutions can then be used to provide recovery plans for standard cases. However, in the general case plans have to be generated from scratch quickly. Therefore, a genetic algorithm has been designed to provide solutions within a few minutes.

4 - Trade-offs Between Vulnerability and Recoverability in Interdependent Infrastructure Networks

Kash Barker, Deniz Berfin Karakoc, Andres Gonzalez

Critical infrastructure networks form the backbone of societies as these networks provide key resources for economic productivity, health, and the way of life of citizens across the globe. Thus, the pre-disruption preparedness and post-disruption recovery of these networks against external stressors represent a vital consideration for risk management given the size and frequency of natural disasters, among other kinds of disruptions. Pre-disruption investments could reduce the vulnerability levels of network components, thus reducing the impact of a disruption. And post-disruption investments could enhance recoverability to more swiftly regain the functionality of networks. Naturally, there exists a trade-off between resources (i.e., time and money) invested before a disruption relative to after. In this study, we extend a resilience-driven multi-objective mixed-integer programming model for interdependent infrastructure network restoration scheduling to account for pre-disruption investment planning to harden network components. This extended version of the model enables an analysis of trade-offs between preparedness and recovery resource investment options for interdependent infrastructure networks, while also examining the impacts of disruptions to communities of varying social vulnerabilities. Finally, the proposed approach is illustrated with a study of interdependent infrastructure networks in Shelby County, Tennessee, USA.

■ MB-43

Monday, 10:30-12:00 - Q114

Facility location I

Stream: Location Analysis and Optimization
Invited session
Chair: *Alfredo Marín*

1 - Locating hyperplanes for multisource linear regression and clustering

Justo Puerto, Víctor Blanco, Alberto Japón Sáez, Diego Ponce

This talk considers the problem of locating a number of hyperplanes in order to minimize the overall aggregation of the residuals taking into account that each data (location) point must be allocated to the hyperplane that induces the minimum residual. In addition, although in many applications the measure of error is given by the vertical distance from the data points to the fitting bodies, we extend that approach considering norm-based distances to account for the residuals. Several objective functions are also considered, among them the sum of squared, the sum, the maximum and the \$k\$-centrum of the distances. This problem extends the classical continuous p-median problem to the case where the facilities to be located are hyperplanes rather than points.

We develop a general mixed integer second order cone formulation to deal with the general problem of locating p hyperplanes and norm-based residuals. In addition, we also give a reformulation based on a set partition representation of the problem that gives rise to a branch-and-price algorithm able to handle larger sized problems. Preliminary computational experiments show the performance of our formulations and the usefulness of the set partitioning approach.

2 - A branch-and-bound algorithm using Lagrangian relaxation to solve the radius formulation of the p-median problem

Minerva Martin del Campo, Sergio García Quiles

The p-median problem is one of the most important problems in discrete location. It was originally defined by Hakimi in 1964 as a network problem and later formulated as an integer linear programming problem by ReVelle in 1970. The most recent exact method to solve the p-median problem is a radius formulation where the problem is formulated as a set covering problem. The algorithm proposed there starts with a partial formulation and develops a row generation technique to add more inequalities as needed. This strategy is embedded in a branch-and-bound algorithm and it is able to solve very large instances with several thousands of nodes. However, it does not work so well for problems with small values of p.

In this work we have developed a heuristic method based on Lagrangian relaxation and branch-and-bound to obtain good solutions. The radius constraint is relaxed to form the Lagrangian dual problem and subgradient optimization was used to solve it. If the full set of radius constraints is relaxed, the dual problem can be solved quickly. This relaxation is used in a branch-and-bound algorithm to find lower bounds at every node. We carry out a computational study to test the efficiency of this method.

3 - Location of Base Stations Considering Changes in Users Locations

Shokri Selim

We consider the classical problem of locating base stations to serve users in a given geographical area. An interesting case is where the user location is expected to change over time. For example, if the users are moving to attend a sports event or a concert in a remote area which is not usually served by mobile stations. Another example, is where a new residential area is being established and it is expected that new extensions will be developed over time. We develop a mixed integer program that finds the optimal location of base stations at different times periods such that the total cost is minimized. A detailed example will be presented.

4 - Shared Facility Location Problem

Mercedes Pelegrin, Alfredo Marín

We consider and study a variant of the classical discrete facility location problem in which decisions are on opening facilities and allocating customers to them. The modifications we introduced are: (i) some pairs of customers must share a facility in order to receive a common service and (ii) every customer has to be allocated to two different facilities. Several integer programming formulations are developed and compared; strategies to tighten the formulations are also explored. Our computational experience shows the practical relevance of our theoretical findings for a wide-ranging test-bed consisting of 200 problem instances.

■ MB-45

Monday, 10:30-12:00 - Q117

Air Transportation I

Stream: Transportation and Logistics
Invited session
Chair: *Sébastien Deschamps*

1 - A hybrid simulation-optimisation approach for scheduling airport ground service equipment
Yagmur Simge Gök, Maurizio Tomasella, Daniel Guimarans, Cemalettin Ozturk, Silvia Padron

Airport ground service equipment (GSE) planning and scheduling problems have taken much interest within the OR/MS community in the past few years. Interest has increased partly because of a sustained growth in the number of scheduled flights and related airport congestion and operational complexity. There are different aspects to approach the GSE planning problem, both ahead and during the day of operation. In this study, we work at the tactical level to develop daily robust allocations of GSEs based on the scheduled flights and foreseeable disruptions. We focus on the uncertainty involved to achieve robust and resilient operations with respect to GSE allocation. We integrate simulation within an overall Simulation-Optimization method, falling within the family of so-called Simheuristics, to deal with the uncertain factors of GSE allocation. The problem has a marked combinatorial nature, where metaheuristics help to efficiently explore the search space and lead towards more robust solutions. Reliability is evaluated thanks to the inclusion of simulation at key steps of the overall methodology, providing feedback to guide the search method towards more robust solutions.

2 - Airline schedule planning under infrastructure constraint and with customer choice evaluation
Sébastien Deschamps, Axel Parmentier

The schedule planning problem aims at choosing the set of flight legs operated by an airline so as to maximize its revenue. The difficulty of this optimization problem is that it links two sub-problems, both challenging on their own. On one side, the planning must be operable with the assets of the airline. An ever growing constraint is the scarcity of slots in hubs in a context where air traffic grows faster than airport infrastructures. And on the other side, evaluating the revenue requires to model demand and customer choices on each origin-destination operated by the company, spill and recover, and decision of the airline revenue management to affect capacity between different itineraries sharing the same leg. Due to connections, the number of itineraries potentially operated is very large. Leveraging a logit model for customer choice, we propose a linear program for this second subproblem that models spill and recover and airline choice. And we integrate it in a mixed integer linear program for the complete schedule planing problem. This problem being challenging for present day MILP solvers, we propose a Benders decomposition approach to solve it.

3 - Flight cost effectiveness of domestic airline flight schedules
Hamdan Al Fazari

This paper considers the planning of flights operated by airlines in a domestic network. It develops a framework to assist the flight manager of a domestic airline in assessing the cost efficiency of a schedule for a given flight plan. The proposed framework is based on the construction of a flight connection graph which is built from the consideration of preceding constraints resulting from the flight schedules, the planned flight connections, the aircraft, and the crew and commercial staff assignment to the flights operated by the airline. Then time margins between successive flights can be computed. An optimization problem is formulated to take efficiently into account in-flight delay absorption capabilities of the considered flights, resulting in a flight cost optimized time table for the flight plan. This leads also to the optimized definition at the domestic network level of the cost indexes assigned to each flight. A medium size case study is developed to illustrate the proposed approach.

4 - Airline crew scheduling with retiming, dynamic aircraft rotation and complex connection rules.
Waldemar Kocjan

Airline crew planning is usually divided into several problems solved separately. In this presentation we consider the crew pairing problem, a task of finding a set of anonymous crew trips covering all the flights. This corresponds to solving the set covering problem. The complex rules which trips needs to follow are influenced by other planning stages like timetabling and fleet planning. Typically, aircraft routes constructed during the fleet planning stage influence crew connection time allowing shorter connection time if the crew does not change an aircraft. Also small adjustments to the timetable may give cheaper crew solutions. On the other hand adjustments to both crew connection and to the time table can make aircraft routing infeasible. Simple connection rules are handled by plane count constraints. Those constraints fail however to maintain aircraft feasibility for more complex rules. In the Jeppesen Crew Pairing system we maintain aircraft feasibility by adding dynamically generated aircraft feasibility constraints. In this presentation we will describe how this is done in practice and what impact does it have on airline planning.

■ MB-46

Monday, 10:30-12:00 - L243

Advances in Variational Inequalities and Equilibrium Problems I

Stream: Variational analysis, games and intertwined optimization problems
Invited session
Chair: Tangi Migot

1 - No-regret learning in time-varying games
Benoit Duvocelle, Panayotis Mertikopoulos, Mathias Staudigl, Dries Vermeulen

In this paper, we examine the long-term behavior of regret-minimizing agents in time-varying games with continuous action spaces. In its most basic form, (external) regret minimization guarantees that an agent's cumulative payoff is no worse in the long run than that of the agent's best fixed action in hindsight. Going beyond this worst-case guarantee, we consider a dynamic regret variant that compares the agent's accrued rewards to those of any sequence of play. By properly adapting a restart procedure pioneered by Besbes et al. (2015) we show that players are able to achieve no dynamic regret against any test sequence whose total variation grows sublinearly with the horizon of play. In particular, specializing to a wide-class of no-regret strategies based on Mirror Descent, we derive explicit rates of dynamic regret minimization, both in expectation and in high probability. We then leverage these results to show that players are able to stay close to a Nash equilibrium in time-varying monotone games and even converge to equilibrium if the sequence of stage games admits a limit.

2 - On first and second order sweeping process
Florent Nacry

Sweeping process has been introduced and studied by J.J. Moreau in 1971 as a constrained first order differential inclusion. Such evolution problems are described through the normal cone of a convex moving set and can be seen as a particular (differential) variational inequality.

Due to its many applications (crowd motion, nonregular electrical circuits, allocation mechanisms in Economics, nonsmooth mechanics,...), various and numerous extensions of the original problem by Moreau has been developed over the years (BV, nonconvex, second order, stochastic, in Banach spaces, perturbed,...).

Roughly speaking, the so-called Moreau sweeping process can be handled in three major ways that we will briefly recall in our presentation: regularization (via ODE), reduction (to an unconstrained differential inclusion) and catching-up algorithm (a kind of Euler's explicit scheme).

This presentation is devoted to the existence of a new evolution problem which encompasses two among the most popular variants of sweeping process. Here, our moving set will be prox-regular in a general Hilbert space and allowed to jump (BV). After giving the necessary preliminaries on prox-regularity, we will focus on the construction (thanks to a suitable new version of the Moreau's catching-up algorithm) of a trajectory solution.

3 - Dynamics of generalized Nash games and evolutionary games
Monica-Gabriela Cojocaru

In this talk I plan to introduce an evolutionary generalized Nash game (eGN). Generalized Nash games were introduced in the 50's, and represent models of noncooperative behaviour among players whose both strategy sets and payoff functions depend on strategy choices of other players.

Among these games, a specific class is represented by evolutionary games, which consist of populations where individuals play many times, against many different opponents, with each contributing a relatively small contribution to the total reward. Given strategies 1, ..., n, an individual of type i is one using strategy i, where xi is the frequency of type i individuals in the population. Thus the vector x = (x1, ..., xn) in the unit simplex is the state of the population. Interaction between players of different types can be described by linear or nonlinear payoffs. One known dynamic evolution of such a game is described by a replicator dynamics. However, assuming constraints imposed on the strategy sets of players (upper limits on resources for instance) the classic replicator dynamics is not appropriate anymore.

In these cases we show that we can reinterpret the game dynamics of an eGN differently. The new dynamics and its relation to evolutionary steady states is investigated.

■ MB-47

Monday, 10:30-12:00 - L247

Behavioural issues in environmental-decision making

Stream: Behavioural OR
Invited session
Chair: *Judit Lienert*

1 - Online survey to test fairness principles for public infrastructure planning
Judit Lienert, Sara Zuercher, Rudolf Vetschera

Public infrastructure decisions affect many citizens. They bring various benefits, but also cause monetary, environmental, and social costs. A fair decision-making procedure resulting in a fair outcome is thus important in this context. Various fairness concepts are presented in the literature, raising the question which concepts are adequate in applications to public infrastructure planning. Our study aims at closing this gap. We conducted an online survey in the German speaking part of Switzerland with 472 respondents. We asked for their perception on fairness principles concerning the decision to change from the current centralized wastewater treatment system to novel decentralized systems. While the latter have many potential advantages, they are not yet widespread in industrialized countries. Our questions aimed at testing principles of distributive justice, namely equality, equity, and need as well as procedural justice. Equality implies that every person receives the same share of a resource, equity that a person receives according to her contribution, and need allowing a person to cover his basic needs. We designed three vignettes illustrating different situations to test these principles. Our hypotheses, based on the literature, were mainly confirmed: Equity was perceived as more fair than equality, implying that ones' contribution should be acknowledged. A decision-making process was perceived as fair, if it complied with the criteria for procedural justice.

2 - Understanding stakeholder learning processes to improve computer technology for forecasting floods in Africa
Francisco Silva Pinto, Judit Lienert

Flooding by large rivers in West Africa is of great concern, projected to increase with climate change. Information and Communication Technologies (ICT) that can forecast flood events and give reliable alarms are of high importance. We present the EU-Horizon 2020-project FANFAR. It aims at adapting such ICT systems to West-African conditions in close cooperation with local institutions. To achieve this, we need to identify user needs and co-develop technologies and capacities. When adapting an ICT system to a specific context, there is an inherent learning process. This can result in behaviour changes of stakeholders that need to be considered for a sustainable uptake. Such changes may be induced by external (e.g. floods during the rainy season) or internal events (e.g. workshops), or differentiated stimuli (e.g. intervention types). To assess learning processes and related behaviour changes in this complex environment, we evaluate its development throughout the project. We will compare a baseline scenario (initial situation regarding operational flood forecasts and alerts) for the main interested actors with their preferences over time. Specifically, to better adapt the ICT system to user needs, we will use an MCDA model and different types of interventions at pinpoint times. Our aim is to understand the learning process in terms of user preferences regarding objectives , the technical system (alternatives), and behaviour changes (perception of/ interaction with system).

3 - Multi-objective survey design for the range-wide assessment of snow leopards
Ian Durbach

Modern wildlife assessment methods make extensive use of non-invasive survey methods such as arrays of cameras or acoustic recorders to estimate the size of animal populations. Decisions about where to place the detectors are often an informed but informal compromise between statistical sampling theory and non-statistical considerations like accessibility and cost, some of which are difficult even to quantify. We report the initial development phases of multi-objective decision support for the first global survey of snow leopards, which samples a vast area of mostly high altitudes and sparse human populations, using surveys to be conducted over several years by a diverse group of governmental and non-governmental organisations, each with their own objectives, regions of interest, and resource constraints. We report the problem structuring approaches used, the formulation of the problem as a multi-objective portfolio optimization problem, and development of interactive software used to assess candidate designs.

4 - Beyond the multicriteria decision aiding process: A post-project monitoring of involved stakeholders in an urban planning case study
Francis Marleau Donais, Irene Abi-Zeid, Edward Owen Douglas Waygood, Roxane Lavoie

Following the development of several multicriteria decision aiding (MCDA) methods over the last decades, numerous decision-aiding tools based on MCDA and group workshops are now used in the environmental field. These MCDA tools are technically accurate and are meant to improve decision processes. Moreover, the development and use of these tools contribute to developing interdisciplinary knowledge or improving communication. However, the lack of post-project monitoring can lead to a misunderstanding of some of these intangible impacts thereby limiting the improvements of MCDA practises. A better monitoring of post-MCDA processes can lead to better adapted decision-aiding tools as a function of the different stakeholders' perspectives and the diversity of their interactions with MCDA tools. This research aims at developing and applying a qualitative strategy to monitor implemented MCDA projects. The cartographic MCDA tool prioritizing the redesign of streets into Complete Streets in Quebec City was analyzed as a case study. Two years after the project, individual interviews were conducted with Quebec City professionals that currently use or have participated in the development of the tool. Further, group interviews with professionals from other cities contributed to our understanding of how a similar project can be applied in different contexts. This research allowed us to identify opportunities and limits to the project, but also solutions to enhance current MCDA practices.

■ MB-48

Monday, 10:30-12:00 - L248

Environment and Finance II

Stream: Applications of Dynamical Models
Invited session
Chair: Alessandro Ravina

1 - A generic multi-commodity heterogenic energy market design for joint balance of energy, reserves, options and transmission rights
Eugeniusz Toczylowski

A generic multi-commodity market design model (Toczylowski 2000) was proved to be a promising theoretical framework for long-term evolutional development and integration of the heterogenic energy market designs. The market segments are in the form of the multi-commodity auctions for improved coordination between renewable and nonrenewable energy, energy options and reserves products, and obligation transmission rights trade, under the DC transmission flow model constraints. The approach allows us to achieve the multi-commodity market balance for joint energy, reserves, options and transmission rights products through joint dispatch/optimization and market clearing.

2 - Firm- and country-level determinants of green investments: An empirical analysis
Stefan Wendt, Thomas Walker, Wangchao Yuan

This paper examines the determinants of corporate green investments (GI) by using a series of both firm- and country-level factors. We use environmental expenditures as a proxy for green investments on a firm level. We find that bigger firms tend to invest more in green projects, whereas firms that are more profitable are less likely to go green. In terms of country-level determinants, we find that GDP per capita and surface area are negatively related with GI, while population is positively associated with GI. Firms in English common-law countries and English-speaking countries invest less in GI than firms in other countries. To verify the results of our country-level determinants, we also perform a country-level test that employs a country's ecological footprint as the proxy for GI. The results of the latter analysis are mostly in line with the results of the firm-level analysis.

3 - What triggers electric vehicle adoption? A cross-country study
Supriya Kumar De, Rajeev Ranjan Kumar, Apalak Khatua

Considering the recent climate change and global warming, the adoption of electric vehicles (AEV) becomes a viable and sustainable option to lower the emission of greenhouse gases. Hence, AEV has gained the attraction of policymakers and academicians. Prior studies have explored various antecedents of AEV which ranges from gasoline or electricity price to population, GDP, education and so on. These studies are mostly from developed economies due to the scarcity of data. In contrary to these studies, we have considered panel data from 21 countries during the period 2011 to 2017, but we observe that for a few countries consistent data is not available for all these years. To overcome the constraint of missing data, we have employed moving average and linear imputation techniques. It is worth noting that most of our variables are trend variables. Hence, we also control for heteroscedasticity and autocorrelation issues in our generalized least squares (GLS) analysis. We have considered total electric vehicles as well as yearly sales of electric vehicles as our dependent variables. Our findings suggest that the trend of AEV is positive during our study period. We note a negative relationship between AEV and CO2 emissions. We also find that the infrastructural environment required for electric vehicles, such as lower batter cost and availability of chargers, enhances AEV. Interestingly, we observe that AEV is challenging in bigger countries with a huge population base.

4 - The impact of low-carbon policy on stock returns
Alessandro Ravina, Rania Hentati-Kaffel

Low-carbon transition risk originates from the attempt to achieve a low carbon economy. It follows that the essential property for an entity to be subject to the risk is GHG emission. This article has a stated objective: it aims at filling a void in the literature by developing an assessment methodology for low-carbon transition risk at portfolio level. The article puts forward an instrument able to capture carbon footprint patterns in average stock returns. This is achieved by providing an environmental extension of Fama and French's five factor model: this specification is directed at capturing size, profitability, investment and carbon footprint patterns in average stock returns and, therefore, include climate change risks into the traditional financial risk analysis framework. The returns to be explained are value weighted excess returns on five clusters (portfolios) of stocks obtained by implementing a K-means algorithm on the STOXX Large index.In the end, due to data availability, 104 stocks have been retained out of 200. The Monthly excess returns considered range from Q1 2000 to Q4 2015. The sensibility of stock portfolios excess returns to environmental policy has been isolated: as expected, carbon intensive portfolios underperform green portfolios in case of aggressive climate policies. The cluster that includes carbon intensive and big capitalization stocks is the most impacted (highest sensibility) by environmental policy.

■ MB-49

Monday, 10:30-12:00 - L249

Software for mixed-integer linear optimization

Stream: Software for Optimization
Invited session
Chair: Timo Berthold

1 - Recent Improvements to the SAS MILP Solver
Philipp Christophel, Imre Polik

The SAS MILP solver is under continuous development to improve its performance and widen the kind of instances it can reliably solve. This talk will discuss recent improvements to parts of the solver such as presolver and simplex implementation and discuss their effect on the overall performance.

2 - RLT Cuts for Mixed Integer Linear Programming
Tobias Achterberg

Reformulation Linearization Technique (RLT) cuts are an important ingredient to solve non-convex mixed integer quadratically constrained problems (MIQCPs). Many solvers for this problem class work on an LP relaxation of the problem, in which the McCormick relaxation is used to linearize the quadratic constraints. To do so, one introduces auxiliary variables to represent the product terms that appear in the quadratic constraints.

The main idea of RLT cuts is to multiply a linear constraint by a problem variable and then substitute the resulting product terms with the existing auxiliary product variables. The resulting constraint is again linear and can be added as a cutting plane to the LP relaxation.

In this talk we show how the same technique can be applied to mixed integer linear programs. Variables that model products of two binary variables or a binary and a non-binary variable are discovered in the MILP model and used to substitute the products in the RLT cut scheme. Computational results are presented to illustrate the effect of these cuts in the current development version of Gurobi 9.0.

3 - CPLEX 12.9: performance, multiobjective and modeling assistance callback
Xavier Nodet

CPLEX 12.9 has been released and brings exciting improvements and new features. In this session, we will present this new version: - more performance on LP, MIP and other problem categories - with multi-objective solve capabilities, you can express hierarchies of objectives and let CPLEX provide you the solution that optimizes the value of the various objectives in this hierarchy, controlling whether degrading an objective is allowed in order to improve on the next ones. - with the new Modeling Assistance callback, you can filter the warnings about your model that CPLEX provides. This allows you to focus on specific parts of your problem, or specific warning types, and help you find devise better models.

4 - Recent developments in the FICO Xpress-Optimizer
Timo Berthold

We will present what is new in the linear, mixed integer and non-linear programming solvers within the FICO Xpress Optimization Suite.

■ MB-50

Monday, 10:30-12:00 - Mason Hayes & Curran

Pricing with competition and sustainability

Stream: Operations/Marketing Interface
Invited session
Chair: *Kathryn E. Stecke*

1 - Sharing Manufacturer's Demand Information in a Supply Chain with Price and Service Effort Competition
Albert Ha, Shilu Tong, Yunjie Wang

We study the incentive for a manufacturer to share private demand information with two retailers who compete on price and service effort under a linear wholesale price contract. Without information sharing, the wholesale price may be distorted upward or downward due to a signaling effect. Information sharing allows the manufacturer to alleviate the signaling effect and influence downstream competition. We derive conditions under which the manufacturer shares information with none, one or both of the retailers. We also conduct sensitivity analysis to investigate the impact of some parametric changes on the information sharing equilibrium outcome as well as the firms' profits.

2 - Designing Pricing Mechanism for Retailers under Competition, Spatial Differentiation and Product Differentiation
Tania Saha, Sumanta Basu, Arnab Adhikari, Megha Sharma

Selection of an appropriate pricing policy plays an instrumental role in the profitability and growth of retailers operating in geographically separated markets. Spatial price discrimination (discrimination based on location) and product differentiation are crucial factors in such a selection. Most of the papers empirically analyzed the impact of product differentiation or spatial differentiation on the pricing decision. Also, they ignore the importance of the joint impact of both these factors on pricing strategy. We use an analytical approach in designing a retailer's pricing mechanism by including both product differentiation and spatial differentiation under competition. In our model, two retailers having monopoly power in their respective domestic market engages in price competition with each another in the international market. We study all the possible scenarios when both the retailers adopt the same pricing mechanism (uniform or spatially-differentiated) and when both select different pricing mechanism (one selects uniform and other selects spatially-differentiated). We study both cases when they take pricing decisions simultaneously and when they take sequentially. For each case, we analyze insights related to the impact of market size, product differentiation, change in pricing mechanism (from uniform to spatially-differentiated or vice-versa) on the price and profitability, along with the conditions associated with dominant and coordinating pricing strategy.

3 - Sustainable or Not? Role of Valuation Uncertainty and Operational Flexibility on Product Line Design
Iva Rashkova, Lingxiu Dong, Weiqing Zhang

The rise of sustainability-conscious consumers has led to record demand for sustainable food products, such as organic, eco-friendly, fair trade, etc. This market trend presents a profit-increasing opportunity for the big food companies, which have dominated the market based on traditional attributes such as taste. Yet, taking advantage of this opportunity is challenging due to lack of information on consumers' valuation of sustainability and increased technological costs. We present a model of a monopolist developing and producing conventional and green products to serve a two-segment market consisting of sustainability-conscious and sustainability-neutral consumers. We identify the mechanisms driving the firm's optimal strategy as cannibalization, including market and quality cannibalization, and sustainability upgrade. The former represents the profit loss from introducing green products, while the latter accounts for the profit gain from sustainability consumption. By disentangling the firm's development and production decisions, we find that the firm might develop conventional products only, but never green products only. Nevertheless, it might decide to produce green products only for the entire market, thus leaving the green segment with a positive consumer surplus. Finally, our model identifies the practice of development waste - resources spent on developing a product that is ultimately not produced.

4 - The on-demand bus routing problem: the importance of bus stop assignment
Lissa Melis, Kenneth Sörensen

Even though public bus transport is still largely bound to fixed routes and fixed timetables, technology would allow for a large-scale shift to on-demand public transport in the near future. In such an on-demand system, buses would drive along routes completely determined by the demand of passengers. To support the routing of on-demand buses we define a new optimization problem: the on-demand bus routing problem (ODBRP), which combines the dial-a-ride problem (DARP) with bus stop selection, introduced in the school bus routing problem. Given a set of requests for transportation, indicating a passenger's departure and arrival location, as well as his/her preferred arrival time, the aim of the problem is to (1) assign each passenger to a departure and arrival bus stop within walking distance, and (2) develop a set of bus routes, picking up passengers at their departure stop and delivering them to their departure stop before their preferred arrival time. The first decision is called bus stop assignment. The goal is to group customers so that the bus can avoid extra stops and detours. This way there is more flexibility for the routing and the efficiency of the system increases. In this talk, we present the ODBRB and we investigate the positive impact of bus stop assignment on the solution quality, using a straightforward heuristic. Further, we determine the parameters (number of requests, fleet size, number of stations, etc.) most influencing this impact.

■ MB-51

Monday, 10:30-12:00 - William Fry

Dynamical Systems and Mathematical Modelling in OR 1

Stream: Dynamical Systems and Mathematical Modelling in OR
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Burcu Gürbüz*
Chair: *Olabode Adewoye*

1 - Modeling multi-stage decision making under incomplete and uncertain information
Viktor Bindewald, Fabian Dunke, Stefan Nickel

We consider multi-stage optimization problems with uncertain future data. Several methodologies are available for this problem class, such as online optimization, multi-stage stochastic programming and multi-stage robust optimization. However, these methodologies all differ in nuances such as end of planning horizon, required data or objective function character. In practice, information about the future is only available for a rather narrow time window and not for the entire decision horizon. Typically, new information is revealed gradually and information concerning later periods is based on forecasts. Hence, the multi-stage problem dissolves into a series of highly coupled snapshot problems that contain uncertain parameters. In this talk we present a new modeling framework for multi-stage problems that incorporates all three methodologies on the snapshot problem level, thus providing the decision maker with a rich toolbox from different fields. Our framework is highly customizable: it allows to switch between methodologies in reaction to changing risk attitudes and covers problems that are event-driven (e.g., scheduling) or time-driven (e.g., lot sizing). Furthermore, our framework allows to study the influence of different algorithms, amount of the available information and applied methodology on the solution quality. In the second part of the talk, first experimental results on the latter questions for specific problems will be presented.

2 - Innovation, diffusion and adoption of Corporate Social Responsibility in health organizations
Alicia Zanfrillo, María Antonia Artola, Luciana Tabone

The evolution of Corporate Social Responsibility (CSR) from the reactive to the proactive approach is based on both external and internal factors where pressure from stakeholders plays a decisive role. The positive relationship between stakeholders participation and performance improvement fosters responsible behaviors to develop positive reputation, trust and community support. In developing countries the pressure exerted by stakeholders in the adoption of an environmental conscience is low with few participation strategies. The purpose of the work is to model the interactions of civil society organizations linked to health services in the city of Mar del Plata (Argentine Republic) in 2018 in order to recognize the effect of the recommendations of the regulatory bodies and the "mouth-to-mouth" in the diffusion of CSR as an organizational innovation. Quantitative research with an agent-based approach was adopted from Bass's mathematical formulation. The influence of the entities that provide information on CSR was simulated considering: a) potential market of entities with digital presence and b) all the entities of the supply chain. The evaluation of the scenarios shows that the structure of the network is significant in the diffusion process, requiring greater attention to the information strategies on the subgroups of entities to achieve the imitation effect.

3 - Applications of a Discount Rate for Project Risk Analysis in Practice
Samuel Bodily, Manel Baucells

We illustrate the use with practical examples of recent results for the appropriate discount rate to use in project evaluation. These examples exhibit a variety of risk structures of uncertainty and show how the traditional finance approach may miss some of the risk nuances that our methods do not miss. In our recent work we have introduced two new discount rates. We introduced the certain return equivalent, ro, to be used when simulating the entire portfolio consisting of a project and stocks and treasuries. Second, we introduced the adjusted discount rate, ra, which would be used to evaluate a project when omitting the stock market uncertainty. In this paper we explore the extent to which ra provides a certain equivalent (CE) that is the same as the correct CE provided by ro, and how these CEs compare to the standard finance expected NPV. We also study how decisions about whether to accept a project and about the portion of a risky project decision variable it is optimal to take compare using ro, ra, and the standard finance approach. The easy-to-use ra aspires to be a very good approximation to the correct CE in simple and more complex situations and we find in these examples that it does succeed. The approach is robust to use with projects presenting wide-ranging structures of uncertainty.

Monday, 12:30-14:00

■ MC-01

Monday, 12:30-14:00 - O'Reilly Hall

Nicole Adler

Stream: Tutorials
Tutorial session
Chair: Ana Camanho

1 - Applying game theory to analyze air transport markets
Nicole Adler

Applying game theory to analyse markets has proven to be a useful methodology to shed light on the aviation supply chain. From airlines, enabling hub-spoke network design to codesharing and alliance formation, to airports, enabling capacity decisions and passenger flows within a terminal, to air traffic control provision, enabling collaborative decision-making and the implementation of new technologies. I will discuss the underlying threads connecting many of the models in the field and then concentrate on a recent Horizon2020 project called COMPAIR. Within this project, we develop a two-stage network congestion game whereby regulators, air traffic control providers and airlines interact. The two stage game utilizes profit maximization and cost minimization models combined with discrete choice functions in order to estimate the best response strategies of all actors in the market. We debate whether it is possible to introduce competition for the market in air traffic control in Europe and the likely outcomes. The game considers an auctioning process in which the regulator sets rules a-priori and the service providers bid for the right to serve the market. We test the likely equilibria outcome if the companies are for-profit or non-profit and the results suggest that introducing competition for the market via outsourcing service provision may reduce charges by up to half the current levels. It would also appear that auctioning the service is likely to defragment the European market as companies win more than one auction. Finally, for-profit companies are highly likely to invest in new technologies thus encouraging adoption faster than appears to be occurring today, helping to accomplish the goals of the single European Skies initiative.

■ MC-02

Monday, 12:30-14:00 - Moore Auditorium

ROADEF/EURO challenge

Stream: ROADEF/EURO challenge
Award Competition session
Chair: Marc Sevaux
Chair: Eric Bourreau

1 - Challenge ROADEF / EURO - Cutting Optimization
Quentin Viaud

The French Operational Research and Decision Support Society (ROADEF) organizes jointly with the European Operational Research Society (EURO) the ROADEF/EURO challenge 2018 dedicated to glass cutting problem in collaboration with Saint-Gobain Glass France, one of the world's leading glass manufacturers. Flat glass is mostly produced through a process called the "float process". At the end of this process, an infinite glass ribbon is cut into large glass sheets (bins). To facilitate the storage, bins are stacked after cutting from the ribbon. These bins are most of the time cut into smaller rectangular pieces (items) adapted to customer needs. These items are cut according to a cutting pattern which satisfies a certain amount of constraints related to the customer (production plan, ...) or to the physics of glass (guillotine cut, cut length limitation). Bins are not perfect and may contain defects inherent to the float process. The goal of this challenge is, for a given sequence of bins and their defects, as well as a given item batch to cut, to propose an algorithm to minimize the glass losses of the cutting process. During this presentation, we will describe the problem, its context and constraints. A more detailed subject, realistic instances and solution checker can be found at urlchallenge.roadef.org. An overall amount of 45.000euro will be distributed to the best contributions.

2 - Hybrid VNS-Simulated annealing heuristic for the ROADEF/EURO challenge 2018
Nicolas Dupin, Franco Peschiera

The "ROADEF/EURO challenge 2018: Cutting Optimization Problem" is studied. It consists of a two-dimensional bin-packing problem with partial sequence constraints, guillotine cuts and defects, among other industrial constraints. The objective is to minimize the number of plates needed to produce the required demand of items to cut. We present an approach based on the combination of two different metaheuristics, namely simulated annealing (SA) and variable neighborhood search (VNS), to solve it. The implemented method takes advantage of the tree structure of the solution to do efficient neighborhood searching and swapping at different hierarchical levels, and conflicts detection and fixing. Experimentation was done on small and large instances of the problem, provided by the organisers. Results delivered feasible solutions for most instances (including more than half of large ones) in less than one hour. In the case of smaller instances, solutions were obtained in less than a minute, as the rules in the challenge conceived.

3 - A new Branch & Bound algorithm for the EURO/ROADEF 2018 Challenge
Luc Libralesso, Florian Fontan

We propose a branch and bound algorithm for the Glass Cutting problem presented by Saint-Gobain at the EURO/ROADEF 2018 challenge. This approach leads to promising results and seems competitive with the other approaches used during the challenge.

It consists of a decision model which enumerates all solutions as trees, node selection criteria and a branching strategy that explores the possible solutions starting by hopefully the best ones. Several trees are explored in parallel with different heuristics. Each time a better solution is found, it benefits all tree explorations. We run in parallel four restarting branch and bounds with different parameters. At the beginning, the algorithm behaves like a greedy random and at the end like a branch and bound. This principle allows to find good solutions first and guarantee to improve with more execution time. Using this principle, we can achieve a good performance for both short and long time runs.

If the instance has a small number of stacks, we can run a dynamic programming inspired approach using an A* algorithm that is guaranteed to provide an optimal solution quickly. This approach is able to return good solutions for instances A17 and B5 in less than a few seconds.

In this talk, we will describe more in details the algorithm, including the general architecture but also the specific cuts allowing us to break symmetries and how to remove dominated partial solutions.

4 - A beam search algorithm for solving the cutting problem of a large glass manufacturing company
Francisco Parreño, Maria Teresa Alonso Martínez, Ramon Alvarez-Valdes

The cutting problem proposed by the glass company consists of two elements, an ordered set of large glass plates, with defects to be avoided when cutting the pieces, and a set of pieces. Among the pieces there is a partial order that divides the set in stacks, and the pieces of each stack have to be cut in order. As we are cutting glass, only guillotine cuts are allowed and the number of cutting stages is limited to three, although an additional cut can be applied to a rectangle to obtain a piece. The first cut is always vertical, dividing the plate into vertical strips. The goal is to minimize total waste in cutting patterns.

We have developed a beam search algorithm. At each node in the tree, a randomized constructive algorithm adds elements to the parent node solution. The procedure depends on three parameters. The first parameter defines the elements to be added to the partial solution, a vertical strip, several strips, or a complete plate. All the candidates are evaluated locally, using as criterion the occupation percentage of the elements added to the solution. The second parameter determines the number of nodes to be selected for the global evaluation that consists of completing the partial solution using the deterministic version of the constructive algorithm. The third parameter determines the number of nodes that are maintained at each level. The parameters change according to a predefined scheme until the time allowed for execution is exhausted.

■ MC-03

Monday, 12:30-14:00 - Q106

Operations Research Meets Machine Learning: highlights from the 2nd conference of the EWG-POR

Stream: Practice of OR (Making an Impact)
Award Competition session
Chair: *Sofiane Oussedik*

1 - Operations Research Meets Machine Learning: highlights from the 2nd conference of the EWG-POR
Matteo Pozzi

More than 100 between OR practitioners and industrial representatives met in Bologna on 11-12th March 2019 for the 2nd conference of the EURO Working Group on Practice of Operations Research to exchange experiences and best practices, with a particular focus on the relationship between Operations research and Machine Learning (and Data Science at large). What came out was the picture of a rapidly evolving business community, rooted in its core skills, but also open to new challenges with a focus to developing increasingly effective Decision Support Systems. This session will report on the event and its key findings, representing an additional chance to foster debate and confrontation about this very actual issue.

■ MC-05

Monday, 12:30-14:00 - A003

OR applications for solidarity economy

Stream: OR for Development and Developing Countries
Invited session
Chair: *Athanasios Rentizelas*
Chair: *Hélio Fuchigami*

1 - Optimization model as a decision support system for participating in public tenders for feeding programs
Hélio Fuchigami, Maico Roris Severino, Athanasios Rentizelas, Andrea Tuni, Lie Yamanaka

Communities of small family farmers are among the poorest and most vulnerable segments of Brazilian society, so any increase in their disposable income would make a significant difference in their living standards. In response to this social problem, Brazilian authorities have developed programs to encourage family farming (such as the PAA - Food Acquisition Program and the PNAE - National School Feeding Program, in English), giving family farmers priority to the provision of agricultural products and food to schools and public institutions. However, farmers face a challenge both in deciding which public calls they subscribe to and in distributing their products to schools and public institutions. They struggle also in identifying which areas and contracts to compete for, leading to reduced participation of vulnerable farmers in government programs specifically designed to support them. To this end, a decision support system (DSS) based on an optimization model was developed to address this problem. The DSS allows farmers to identify which bids to attend based on a two-phase-gate process, which evaluates bids based on their individual profitability as well as on a geographical area value concentration critera.

2 - Optimising the product distribution decisions for government feeding programs in developing countries
Athanasios Rentizelas, Maico Roris Severino, Hélio Fuchigami, Andrea Tuni, Isotilia Costa Melo

Institutional markets have evolved as one alternative way for smallholder farmers to access the market and supply their produce at a known in advance price and quantity. This helps planning agricultural operations and provides security of income, which is critical for the farmer livelihoods. One such example is the PNAE government feeding program in Brazil, where schools source raw materials and ingredients from local smallholder farmers for school meals. This work presents a Decision Support System (DSS) supporting farmers decisions on which schools to supply, with which products and how to organise the logistical activities, to maximise the net income from participation in these markets. The DSS is applied after the farmers have knowledge which bids they have been successful in, and therefore they have clarity on the potential supply areas. The decisions at this stage can be quite complex, with several factors to be considered simultaneously, such as product range, quantities and price for each school that a bid was won, distance and logistical costs, and logistical synergies when delivered quantities in the same area are larger. At the same time there are constraints such as the land, transportation and resource availability. The proposed DSS is novel in supporting smallholder farmer decisions on supplying institutional markets. The results of the DSS application for a specific smallholder farmer settlement in Brazil are presented and discussed, to assess its applicability

3 - Supporting decisions of smallholder farmers on public calls participation in Brazil: A Data Envelopment Analysis approach
Paulo Nocera Alves Junior, Isotilia Costa Melo, Maico Roris Severino, Lie Yamanaka, Andrea Tuni, Athanasios Rentizelas

Brazilian authorities have developed programs to encourage smallholder family farmers to supply food to schools by giving them priority through the government food procurement programs, which are an example of institutional markets. However, the participation of vulnerable farmers to these programs is often limited by scarce resources that do not allow farmers attending all public calls, so it is necessary to support them in deciding which ones to attend, considering their objectives and constraints, and identifying the efficient ones. The aim of the paper is to support the decision making of choosing these public calls, by the vulnerable farmers. This will be done using Data Envelopment Analysis (DEA) to rank the public calls (these public calls will be the model's Decision-Making Units - DMUs) using the relative efficiency as a ranking criterion. One hypothetical DMU with minimum expected values could be considered, so the efficient calls (i.e. the ones that surpass the minimum expected) will be considered for application. In a second stage, a tiebreaking method is used to rank only the efficient ones, so they can choose only the best ranked efficient calls if there are resource constraints. An empirical application using calls from the National School Meal Program (PNAE) will be made using the developed model. The main contribution is helping smallholder family farmers to make more grounded decisions.

4 - An approach to select public bids based on ELECTRE TRI, triangular hesitant fuzzy and ELECTRE III to support the decision-making of family farmers
Andrea Tuni, Nadya Regina Galo, Maico Roris Severino, Hélio Fuchigami, Lie Yamanaka

This work proposes a multi-criteria approach to support small family farmers to evaluate public bids of the National School Feeding Program (PNAE) in Brazil, in order to identify the bids in which family farmers are most likely to be selected. PNAE is a governmental program to offer meals and food education to students of public and basic education. In this program, family farmers compete in municipal and state public bids to supply food to public schools. However, farmers need mechanisms to decide which calls to attend, considering production capacity and forecasted chances of winning the bids. To support this decision, this work proposes the use of ELECTRE TRI to categorise public bids in relation to the competitiveness level of farmers (low, medium and high), in accordance with the priorities and rules established by the calls. Bids categorised at the high competitiveness level need then to be ranked to establish an order of preference. Adopting weighted criteria derived from farmers to evaluate the public bids, Triangular Hesitant Fuzzy is then used to aggregate linguistic judgements and transform them into numerical values to be used as inputs of ELECTRE III. The final ranking of public bids is obtained through ELECTRE III. The approach is embedded in solidarity economy and is functional to support the decision-making of family farmers in public bidding participation, potentially helping them to improve their income and standard of living.

■ MC-06

Monday, 12:30-14:00 - A004

Equilibrium Models for Energy Systems Analysis

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Mel Devine

1 - Discretely Constrained Equilibrium Models in Energy and Transportation
Steven Gabriel, Martin Schmidt

We present the discretely constrained mixed complementarity problem (DC-MCP) which combines both integer and equilibrium aspects. Theoretical results are presented based on re-expressing the problem as the zero of a certain median-based, non-smooth function and then re-expressed as a particular mixed-integer nonlinear program (MINLP) whose solutions matches that of a DC-MCP. Numerical results in energy and transportation are presented to show the applicability of this class of problems.

2 - Modeling the Role of Cross-Border Energy Infrastructure in Resilience to Natural Gas Price Shocks
Sauleh Siddiqui

Low-cost supply from shale gas production along with the transition to a low-carbon economy has led to natural gas becoming the main fuel for electricity production in North America, and the leading source for electricity production in both the United States and Mexico. This increased dependency on natural gas leaves North America vulnerable to shocks in natural gas supply, with different regional supply and demand characteristics amplifying questions of resilience. In this presentation, we model the role of cross-border infrastructure — natural gas pipelines and electricity transmission lines — on energy resilience in North America using an equilibrium framework. In particular, we analyze how expected cross-border infrastructure investments will help or hinder regional prices, welfare, and profits. We couple the North American Natural Gas Model (NANGAM); a partial-equilibrium model for natural gas production, transport, storage, consumption, and infrastructure; with the Regional Energy Deployment System (ReEDS 2.0); a high-fidelity, high-spatial resolution model that determines regional capacity expansion and dispatch for electricity; in order to understand the dynamics of this cross-border infrastructure development under different scenarios of shocks to natural gas supply. The results from this presentation are part of the broader Energy Modeling Forum (EMF 34 Study) led by Stanford University.

3 - Equilibrium models for modelling an oligopoly with a competitive fringe
Mel Devine, Valentin Bertsch, Sauleh Siddiqui

Sellers in a market have market power when they can strategically maximise their profits by influencing the level of demand through the selling price they set. Such behaviour often occurs in wholesale electricity markets and thus Mixed Complementarity Problems (MCPs) are typically used to model them. In this talk, we present a stochastic MCP that models an electricity market consisting of an energy market, a capacity market and a feed-in premium. Market power is characterised by an oligopoly with competitive fringe where large generators can exert market power while other smaller generators cannot. The model is applied to the Irish power system in 2025 and the results show how load shifting demand response can reduce the negative effects of market power. However, the model only considers operational decisions and not long-term investment decisions. When the MCP is extended to incorporate investment decisions, myopic and unrealistic behaviour is observed. To overcome this issue, we also present a stochastic Equilibrium Problem with Equilibrium Constraints (EPEC) model and detail how market power influences investment decisions. However, EPECs are much a more complex model and thus cannot model the same level of operational detail as an MCP. Consequently, we also discuss the modelling trade-offs between using an MCP and an EPEC when modelling electricity markets characterised by an oligopoly with a competitive fringe.

4 - Inverse equilibrium analysis of oligopolistic electricity markets
Simon Risanger, Stein-Erik Fleten, Steven Gabriel

For systems in equilibrium, we can often accurately observe the outcomes, but not what motivates them. A prominent example is electricity markets, where we can observe the bids and prices made by the producers, but not their motivation for making them. This poses a challenge when we try to formulate realistic equilibrium models, where we require accurate parameters. As a response, we investigate the potential of inverse equilibrium models where observed equilibrium states are input used to estimate objective function parameters. We illustrate the method on two applications; a generic Nash-Cournot game and a game where price-making producers compete against each other subject to power system restrictions.

■ MC-07

Monday, 12:30-14:00 - A007

Stochastic Modeling and Simulation in Engineering, Management and Science 1

Stream: Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: *Gordon Dash*
Chair: *Gerhard-Wilhelm Weber*

1 - Adaptation of Standard Anglo-Dutch Auction for TV Broadcasting Licensing: A Simulation-Based Comparative Study
Dimitrios Emiris, Charis Marentakis

Auctions have been used widely in many countries for the licensing of public goods. Amongst various auction mechanisms, in 2002 auction expert Paul Klemperer proposed a hybrid auction mechanism, the so-called Anglo-Dutch, which combines the properties of two fundamental auction types the English and the Dutch auction. Since then, various authors commented positively on this hybrid auction format, yet the number of applications was quite limited. In 2017 Greek Government applied a modified format of the Anglo-Dutch auction to award 4 TV broadcasting licenses to equal providers with amazing results in terms of financial outcome, fairness and process transparency, resulting to revenues between 14,5 and 25,3 times the start price of the auction. This innovative auction scheme was largely designed by one of the authors. The major difference between the standard Anglo-Dutch format and the modified one, is that the auction ran sequentially instead of simultaneously. The present article compares the outcomes between the standard Anglo-Dutch and the modified one in terms of revenue and winner determination ranking. A decision model has been developed based on ex-post results which serve as the basis for a series of Monte Carlo simulations used to evaluate the actual results in comparison to the standard Anglo-Dutch auction. Based on the results: a. the modified auction yielded higher revenue and, b. Monte Carlo simulation is a quite effective method for the design of auctions.

2 - Application of State Space Models to Financial and Economic Data
Miaad Alqurashi

In dynamic modelling of financial and economic data the concept of cointegration plays an important role. It refers to the existence of long-term equilibrium relations between financial/economic variables in a dynamic environment. In the literature so-called VAR modelswith cointegration are popular. In its Edgeworth Centre, University College Cork are developing parameterization/estimation methods for alternative models, namely State Space models with cointegration. The research topic in this project is to study cointegration of financial data and how a state space representation of these processes can be constructed. We will first start off by giving a brief introduction on cointegrated I(1) processes before explaining further the VAR model. After laying out the groundwork of the Engle and Granger approach and of Johanson's work using the VAR model, we will consider how a state space representation of the cointegration model using a maximum likelihood criterion can be beneficial as opposed to Johanson's VAR model. We introduce the state-space error correction model (SSECM) and discuss in detail how to estimate SSECMs by maximum likelihood methods, including reduced rank regression techniques which allow for a successive reduction of the number of parameters in the original constrained likelihood optimization problem. Finally, the remaining free parameters will be represented using a new local parametrization technique which has several advantages.

3 - Simulation-Based Optimisation for More Effective Big Data Placement in Hadoop
Takfarinas Saber, Leandro Almeida, Anthony Ventresque

Big Data platforms, such as Hadoop and Spark, have been around for more than a decade now - and they are popular in the industry as well in academia. Those services are based on reliable and effective distributed algorithms but there are scenarios and conditions that can generate bottlenecks and inefficiencies. In particular, the placement of blocks in Hadoop Distributed File System (HDFS) that is used by most Big Data platforms, has an important impact on the performance of the system. In order to test solutions to improve the performance of HDFS, we use in our research a simulator that models accurately the behaviour of those platforms at scale. This allows us to test large numbers of configurations without the (costly and time-consuming) need to set up real systems. The set of these block placement configurations defines our (very large) search space. Running Big Data jobs in our simulator on the configurations gives us the performance of each placement. We can now use metaheuristics to explore the search space and select the surrogate objectives that lead to the best placements.

4 - Density estimation by Monte Carlo and quasi-Monte Carlo
Pierre L'Ecuyer

Estimating the density of a random variable X has been studied extensively for settings where a set of n observations of X (the data set) is given a priori and one wishes to estimate the density from that. Popular estimators include histograms and kernel density estimators (KDE). In this talk, we are interested in a situation where the observations are generated by Monte Carlo simulation from a model. We generate a sample and estimate the density from the sample. Then the question arise of whether variance reduction methods such as stratification or randomized quasi-Monte Carlo (RQMC) can be exploited to make the sample more representative, and produce a more accurate density estimator for a given sample size. We provide both theoretical and empirical results on the convergence rates for histograms and for kernel density estimators, when the observations are generated via RQMC. We also examine the combination of RQMC with a conditional Monte Carlo approach to density estimation, defined by taking the stochastic derivative of a conditional cdf of X. This approach can provide a large improvement when it applies.

■ MC-08

Monday, 12:30-14:00 - A008

Design of Humanitarian Systems

Stream: OR in Humanitarian Applications
Invited session
Chair: Sibel Salman

1 - Management of Interdependent Infrastructure Networks under Disaster-related Uncertainties
Sakine Batun, Tugce Canbilen, Melih Çelik

After a disaster, multiple infrastructures have disruptions in their services. During the restoration of these services, we need to consider the operational and restoration independencies among these infrastructures. In this study, the problem under consideration is Interdependent Infrastructure Restoration with disaster related uncertainties. We propose a two-stage program for this problem. First stage makes reinforcement decisions on the arcs of the network while second stage schedules the restoration activities considering the available resources and inherent interdependencies in the network. We will present our computational tests and preliminary results in the presentation.

2 - On the logistics of cash transfer program for Syrian refugees in Turkey: A bi-objective location routing model
Ramez Kian, Gunes Erdogan, Sander De Leeuw, Muhittin Hakan Demir, Ehsan Sabet, Sibel Salman, Bahar Yetis Kara

In this study we address a humanitarian logistics problem connected with the Syrian refugee crisis. Besides in-kind humanitarian aids, cash-based interventions play an important role in helping the suffering victims. We propose a multi-level network consisting of a central registration facility, local temporary facilities, mobile facilities and vehicles for door-to-door visits. The aim is to reach the maximum possible number of eligible beneficiaries within a specified time period under a certain logistics budget. We provide a location routing model to optimize inter-related facility locations, and routing decisions for a bi-objective mathematical model. A case study of Syrian refugees' registration process in southeastern part of Turkey, which administered by the Turkish Red Crescent, is also provided along with the derived insights.

3 - Re-configuring Optimal Mix and Inventory for Multiple-items, Multiple-locations in Humanitarian Relief Distribution
Ali Engin Dorum, Mahmut Ali Gokce

An important part of disaster operations management is relief efforts that take place after the disaster. Humanitarian logistics deals with planning and implementing flow of relief goods such as food, clothing water etc. from storage to victims of the disaster. Due to big unexpected disasters during the last couple of decades, humanitarian logistics has attracted significant research attention from the field of Operations Research and specifically combinatorial optimization. Models that finds out the best possible storage locations and/or optimal distribution of the stored goods, based on the estimated demand after a disaster exists. Unfortunately, sometimes the stochastic nature of disasters, (either in location or intensity or both) and secondary disasters, leaves plans made beforehand hardly optimal. The relief efforts, then, have to continue based on location-inventory decisions made optimally for another problem. An important opportunity exists, if the problem of reconfiguration of mix and inventory of items can be solved optimally and quickly after the actual disaster happens. In this study, we present a new model to reconfigure the optimal mix and inventory of items while the deliveries continue, for a multi location multi commodity setting after a disaster.

4 - Sustainable immunization systems in low and middle-income countries (LMICs)
Catherine Decouttere, Nico Vandaele

Reaching Sustainable Development Goals' (SDGs) health targets relies on health system performance. In LMICs outbreaks of vaccine-preventable infectious diseases are still responsible for high neonatal and under-five mortality rates. National immunization programs' outcomes heavily depend on vaccine availability, donor funding and supply chain performance. Due to growing populations and new vaccine introductions, the immunization systems experience increasing pressure leading to vaccine stock-outs, vaccine wastage and children missing timely immunizations. Multiple stakeholders are involved in decision making and execution to ensure availability of funding, vaccines and immunization services. They include children and caregivers, communities, national government, vaccine distribution partners and manufacturers, donors, NGOs, WHO and UNICEF. Each of them represent a diversity of interdependent actors in the system, connected via feedback loops and delayed outcomes. In order to redesign immunization systems for sustainability, a conceptual model based on systems thinking is proposed. It serves as an advocacy and communication tool for system design and scenario generation. It shows a holistic system view, enables detection of root causes of system failures, facilitates priority setting and confronts policy makers to actual and future exogenous impacting phenomena.

■ MC-09

Monday, 12:30-14:00 - B006

DEA applications in Banking and Finance

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Joseph Paradi

1 - Measuring the employee productivity in a retail bank - an axiomatic non-parametric approach
Juha Eskelinen, Markku Kuula

We examined the relationship between employee well-being and productivity at Nordea, a leading Nordic financial services group in a multidisciplinary research project. As a part of this project we developed a model to measure productivity of the front office employees.

Inspired by the network approach of DEA we divided the work into two activities: Activity 1 converts the working time to customer interactions and Activity 2 converts the customer interactions to sales of various financial services. The overall productivity evaluation is based on the performance at these two activities.As Activity 2 is a single input -multiple outputs case we used the axiomatic estimation of the production function and applied the convex non-parametric least squares (CNLS) regression.

We used data from the bank's Human Resource and Sales Performance Management Systems and estimated the productivity of 537 employees in three different job roles. The employee productivity indicators were combined with employee survey data. The results confirmed a significant positive link between employee well-being at work and productivity.

The employee productivity measurement developed in the project can be applied not only in banking but also in customer services and sales work in other industries.

2 - An analysis of the bank merger gains using the directional distance function model with undesirable outputs
Takayoshi Nakaoka

Merger gains in the banking industry have been debated among researchers and practitioners for the last two decade. However, it is still controversial and unclear whether the merger contributes the efficiency improvement in the banking production process or not. In this paper, we apply to the Directional Distance Function (DDF) model with undesirable outputs for measuring banks' production efficiency score and examine the effect of the mergers on the efficiency. Using a sample of Japanese banks during the merger wave in the 2000s, we show that production efficiency for merged banks increases after the merger events. Furthermore, we find that the efficiency gains depend on the merging bank asset sizes, board member sizes, and the degree of overlapping of branch networks.

3 - Data Envelopment Analysis of Indian Public-Sector-Undertaking Banks and their Current Ranking
Badri Toppur, Ramamurthy Ramakrishnan

India has witnessed the enforcement of deregulation in 1991, and demonetization of high denomination notes, as recently as 2016. Latest Bank data in the form of financials statements, and statistical tables for all groups of banks is provided courtesy of the regulatory bank, Reserve Bank of India. We have identified key output and input variables with financial and operational performance measures in mind. The selected data is standardized so that the regression coefficients are easier to interpret. The correlation of output variables with various managerial and bank factors are determined, to note which factors are significant. Furthermore, price ratios available from solving Output Maximization Primal DEA LPs are also used in a regression analysis with the efficiencies as the response variable. This helps one to gauge trade-offs between the performance metrics. Issues of Technical and Scale Efficiencies are an idea from comparisons of production units. These lead to models appropriate for variable returns to scale (VRS) and constant returns to scale (CRS). We examine, their relevance in the banking sector in the context of borrowing, lending and investment practices.

4 - Leveling the Playing Field for Cultural Differences in Bank Branch Analysis
Joseph Paradi

Traditional Data Envelopment Analysis (DEA) methodology requires a consistent infrastructure and operating environment which one may deem as the "culture" in efficiency studies. Nevertheless, in reality there is a need to compare the units under different environmental conditions. Some units may have an advantageous environment which the others cannot adopt. This research evaluates productivity efficiency across different banks' branches in the Mississauga, Ontario, Canada area. It overcomes the above limitation by a mathematically handicapped DEA model developed here. Finding a handicapping function which can fairly assess the large Canadian banks' differences was one of the contributions of this work. The handicapping approach ensures that the bank's ability to produce financial products at the customer level is the same for all the banks. Furthermore, peer and target analyses are carried out to identify the outliers. In addition, the handicapped approach can be applied to any situation where normal DEA analysis can be used.

■ MC-10

Monday, 12:30-14:00 - H0.12

Applications of Robust Optimization

Stream: Robust Optimization
Invited session
Chair: Aurelie Thiele

1 - Robust Portfolio Optimization with European Options
Aurelie Thiele, Hedieh Ashrafi

We consider the problem of maximizing the worst-case return of a portfolio when the manager can invest in stocks as well as European options on those stocks, and the stock returns are modeled using an uncertainty set approach. Specifically, the manager has a range forecast for each factor driving the returns and a budget of uncertainty limiting the scaled deviations of these factors from their nominal values. Our goal is to understand the impact of options on the optimal portfolio. We present theoretical results regarding the structure of the optimal allocation, in particular with respect to portfolio diversification. We compare our robust portfolio to several benchmarks in numerical experiments and analyze how the optimal allocation varies with the budget of uncertainty. Our results indicate that our approach performs very well in practice.

2 - Increasing Sustainability of Electric Power Planning under Uncertainty
Gianmaria Leo, Aakanksha Joshi, Tim Bohn, Sumit K Bose, Susara van den Heever, David Thomason

The electric power planning is a critical decision-making process, which aims to achieve the right trade-off between safety, continuity of energy supply and sustainability. This business practice is often challenging, since uncertain demand and operational conditions have remarkable impact. The problem often becomes more complex with the presence of renewable sources: increased risks of supply disruption or energy spillage often arise due to the high variability of renewable generation. Our work focuses on a system serving a restricted isolate electric grid, managed by a major European electricity provider. Our Predictive-Prescriptive pipeline supports the entire process. We introduced a Robust Optimization approach reducing costs while improving sustainability. We compared this new approach with more typical solutions adopted in production, by performing an ex-post analysis of different planning recommendations over twenty days of operations. The introduced Optimization model is computationally effective, providing high-quality daily plans in less than one second.

3 - Generating Hard Instances for Robust Optimization
Marc Goerigk, Stephen Maher

While research in robust optimization has attracted considerable interest over the last decades, its algorithmic development has been hindered by several factors. One of them is a missing set of benchmark instances that make algorithm performance better comparable, and makes reproducing instances unnecessary. Such a benchmark set should contain hard instances in particular, but so far, the standard approach to produce instances has been to sample values randomly uniformly.

In this paper we introduce a new method to produce hard instances for min-max combinatorial optimization problems, which is based on an optimization model itself. It can be applied to any combinatorial problem and is very easy to adapt. We show that it is possible to produce instances which are up to 500 times harder to solve for a state-of-the-art mixed-integer programming solver than random instances.

Our plan is to collect a wide variety of hard robust optimization instances, and to make them available to the research community via a dedicated webpage, "www.robust-optimization.com".

4 - Towards the Extremes: The Best Scenario of an Interval Linear Program
Elif Garajová, Milan Hladik

Interval linear programming provides a rigorous mathematical model reflecting vagueness and uncertainty present in real-world optimization problems. Instead of considering exact input data, it is assumed that the coefficients of the linear program can be perturbed independently within the given intervals and the whole family of such possible scenarios is examined. One of the essential questions addressed in interval optimization is the problem of computing the optimal value in the best and the worst case. The worst optimal value of an interval linear program in standard form is achieved for an extremal scenario, in which all coefficients are set to their respective lower or upper bounds. However, this is not true for the scenario corresponding to the best optimal value, in general. In this talk, we will study the structure of the best-case scenario with respect to the extremal values of the interval coefficients. Apart from general interval programs, we will take a closer look at interval transportation problems with uncertain supply and demand in order to derive stronger results on the number of extremal values in the best-case scenario.

■ MC-11

Monday, 12:30-14:00 - H1.12

Vector and Set-Valued Optimization III

Stream: Vector and Set-Valued Optimization
Invited session
Chair: *Miguel Sama*

1 - Scalar and vector optimization on Riemannian manifolds
Gabriel Ruiz-Garzón, Rafaela Osuna-Gómez, Antonio Rufián-Lizana, Beatriz Hernández-Jiménez, Jaime Ruiz-Zapatero

This work studies the behavior of generalized convex functions on Riemannian manifolds motived by the potential of some constrained optimization problems to be seen as unconstrained ones from the Riemannian geometry point of view. Necessary and sufficient optimality conditions for scalar and vector optimization problems are successfully obtained in a Riemannian framework, thus, allowing us to characterize functions for which every critical point is optimal for a mathematical programming problem on Riemannian manifolds.

2 - Stability for the alternating projections method.
Carlo Alberto De Bernardi, Enrico Miglierina

The 2-sets convex feasibility problem is the classical problem of finding, using iterative methods, a point in the intersection of two closed convex sets A and B in a Hilbert space. Many concrete problems in applications can be formulated as a convex feasibility problem.

The method of alternating projections is the simplest convergence result and goes back to von Neumann. During the talk we present some results concerning stability properties of the alternating projections method for the convex feasibility problem in Hilbert spaces. Let us consider two sequences of sets converging to A and B, respectively (with respect to a suitable notion of set convergence). Under additional geometric assumptions on the limit sets A and B (involving locally uniformly rotundity), we provide some stability result for the "perturbed alternating projections method", that is, the sequence given by projecting on the perturbed sets.

3 - Scalarizations of a robust vector optimization problem
Lorenzo Cerboni Baiardi, Elisa Caprari, Elena Molho

Uncertain optimization problems can be tackled by means of the robust approach (introduced by Ben-Tal and Nemirovsky (2002)), which hedges the decision maker against worst scenarios that may occur as uncertain parameters vary within their domains. In this work we investigate the relationship subsisting among the solutions of the set-valued robust counterpart of an uncertain vector optimization problem and the solutions of the robust counterpart of uncertain scalar programs obtained through scalarization of the original uncertain problem. Under suitable conditions, we prove the equivalence between the solutions of the set-valued robust counterpart of the original vector optimization and the robust solution of its uncertain scalarization.

4 - Kaliszewski dilating cones in infinite dimensional spaces
Miguel Sama, Lidia Huerga, Baasansuren Jadamba

This talk will focus on dilating cones in infinite dimensional spaces. It is well known the importance of families of dilating cones in vector optimization. In this sense, Henig introduced a family of dilating cones in order to define a new notion of proper efficiency in multiobjective optimization (Proper efficiency with respect to cones, J. Optim. Theory Appl. 36 (1982)), while Borwein and Zhuang extended this idea to infinite-dimensional spaces (Superefficiency in vector optimization, Trans. Amer. Math. Soc. 338 (1993), no. 1, 105-122). In the same way, Kaliszewski proposed a family of dilating cones by polyhedral cones in finite-dimensional spaces (Quantitative Pareto analysis by cone separation technique, Kluwer Academic Publishers, Boston, 1994). This construction is especially interesting because the dilating cones can be expressed in terms of matrices that make them quite tractable numerically. In this talk we show an extension of the Kaliszewski dilating cone to general infinite dimensional spaces and we study its main properties. Finally we give some examples and an application in infinite dimensional optimization.

■ MC-12

Monday, 12:30-14:00 - H1.51

Network flow algorithms and more

Stream: Combinatorial Optimization I
Invited session
Chair: *James Orlin*

1 - Improvements in max flow algorithms
James Orlin

We discuss 65 years of improvements in running times for solving the max flow problem.

2 - The min cycle problem and the min cycle mean problem
Antonio Sedeño-Noda, James Orlin

We consider the problem of finding the minimum cost cycle in a directed network. In 2017, we showed that the problem can be solved in O(nm) by first solving the min cycle mean problem, and then solving a sequence of shortest path problems. In computational tests, the bottleneck operation was the time it takes to find the min cycle mean. In this presentation, we show how to speed up the time for finding the min cycle mean and thus the time to find a min cost cycle.

3 - Solution Attractor of Local Search: the Key to Global Optimization for the Traveling Salesman Problem
Weiqi Li

The Traveling Salesman Problem (TSP) is often treated as the prototypical NP-hard combinatorial optimization. Global optimization is concerned with the computation and characterization of global optimal points in the solution space. This paper uses the attractor-based search system to solve the TSP globally. The search system consists of two search phases. The first phase uses a local search procedure to produce a small solution region, called solution attractor, in the solution space. The second phase searches the solution attractor completely. The attractor-based search system can solve the TSP much efficiently with optimality guarantee. It also meets the global optimization requirement; that is, it can find all optimal solutions in the solution space.

■ MC-13

Monday, 12:30-14:00 - H2.12

Discrete and Global Optimization III

Stream: Discrete and Global Optimization
Invited session
Chair: *Jan van Vuuren*
Chair: *Gerhard-Wilhelm Weber*

1 - Convex extensions and functional representations of new classes of combinatorial matrices in discrete optimization
Oksana Pichugina, Liudmyla Koliechkina

Numerous real-world problems enable formulation as optimization ones on combinatorial configurations such as permutations, partial and signed ones. To solve these problems to optimality using classical optimization theory, an embedding of a feasible domain in Euclidean space and algebraic reformulation of the problems in continuous variables are required. A highly effective technique to do this is switching to considering combinatorial matrices, such as permutation ones (PMs). We extend the well-known class of PMs and a relatively new one of multi-PMs (MPMs) by sets of partial PMs, partial MPMs, signed PMs and signed MPMs. Algebraic topological and extreme properties of the sets and their convex hulls are studied. For instance, being Boolean, the sets are: vertex-located, i.e., coincide with a vertex set of their convex hull; spherically-located, i.e., are inscribed into a hypersphere; well-described, i.e., enable to solve linear optimization and projection problems effectively. Also, these sets allow convexification of any function defined on them, hence applying convex analysis to optimization on them. A connection of the matrices' sets with numerical and vector sets of permutations, partial and signed permutations is established. It allows using Theory of continuous functional representations in forming extended formulations of combinatorial optimization problems (COPs). As a result, we extend significantly a class of COPs with known Euclidean continuous formulations.

2 - Solution Methods for a Min-max Facility Location Problem with Regional Customers Considering Closest Euclidean Distances
Umur Hasturk

We study a facility location problem where a single facility serves multiple customers each represented by a (possibly non-convex) region in the plane. The aim of the problem is to locate a single facility in the plane so that the maximum of the closest Euclidean distances between the facility and the customer regions is minimized. Assuming that each customer region is mixed-integer second order cone programming (MISOCP) representable, we firstly give an MISOCP formulation of the problem. Secondly, we consider a solution method based on the Minkowski sums of sets. Both of these solution methods are extended to the constrained case in which the facility is to be located on a (possibly non-convex) subset of the plane. Finally, these two methods are compared in terms of solution quality and time with extensive computational experiments.

3 - A study of two mathematical optimization models for activities of the sugarcane supply chain
Socorro Rangel, Eduardo dos Santos Teixeira, Helenice Silva

Sugarcane is a product of great economic relevance. Besides its use for the production of different types of sugar, it is also a renewable source for the production of bio-fuels, bio-products and electricity. The raise of international competitiveness, the fall in the price of products derived from sugarcane and the competition with alternative forms of sweeteners and fuels have posed new challenges to the sugarcane industry. Mathematical optimization models can be useful to support the decisions associated to the activities of the sugargane supply chain, helping to address these challenges. In this work we present a brief literature review of mathematical optimization models that represent the four main stages of the sugarcane supply chain: planting, harvesting, transportation, and industrial processing. In addition, we highlight errors and propose reformulations to two mathematical optimization models presented in the literature. (Thanks are due to the Brazilian agencies FAPESP (2016/01860-1, 2013/07375-0) and CAPES.)

4 - Solving a bi-objective location problem with genetic algorithms
Javier Alcaraz, Mercedes Landete, Juan Francisco Monge, José L. Sainz-Pardo

The Reliability Fixed-Charge Location Problem considers that some of the facilities may become unavailable and two different objectives must be minimized: the sum of the opening and transportation cost if none of the facilities fail and the expected transportation cost. Usually, these different targets are combined in a single objective function, but if the aim of the decision maker is to obtain a diverse set of non-dominated optimal solutions properly distributed along the Pareto-optimal front, then such procedure would not be effective. We have designed and implemented an evolutionary multi-objective algorithm based on non-dominated sorting which exploits the peculiarities of the problem and obtains a set of solutions that are properly distributed along the Pareto-optimal frontier. The encoding and operators employed in the algorithm have been carefully designed, incorporating problem-specific knowledge in order to reach quality solutions in a reasonable computation time. We have carried out an extensive computational experience comparing the results given by the metaheuristic with those obtained by an exact procedure. This comparison demonstrates the outstanding efficiency of the proposed algorithm.

■ MC-14

Monday, 12:30-14:00 - H2.20

Mixed-Integer Programming for Air Transportation

Stream: Mixed Integer Programming
Invited session
Chair: Imke Joormann

1 - Airplane Boarding: Complexity, Approximation and Exact Solution
Andreas M. Tillmann, Felix J. L. Willamowski, Marco Lübbecke

We consider the task of finding a minimum completion time sequence for passengers to board an aircraft. Although this problem has been investigated in the literature before, there seems to be a lack of rigorous theoretical understanding as well as exact optimization methods which reliably handle difficult-to-model aspects such as passenger interference in airplane aisles or rows during boarding. We prove strong NP-hardness of the aircraft boarding problem, derive approximation guarantees for some popular heuristic schemes and introduce two exact mixed-integer programming models which explicitly incorporate aisle blockage constraints. The approaches are evaluated by extensive numerical experiments.

2 - Assigning Pilots to Airplanes using Bulk-Robust Optimization
Matthias Walter

We consider the problem of assigning pilots to airplane crews. To Guarantee availability of the airplanes we propose a bulk-robust approach in which an explicit list of failure scenarios (of pilots) is given and a cost-minimum subset of pilots that allows an assignment of pilots regardless of the failure scenario must be chosen. We compare two MIP formulations and use problem-specific cutting planes in order to obtain optimal solutions in reasonable time.

This is joint work with David Adjiashvili, Viktor Bindewald, Dennis Michaels and Lars Klöser.

3 - Scheduling Aerial Refueling Operations
Imke Joormann, Christoph Hansknecht

We consider the problem of scheduling cruisers in the context of (civil) air-to-air refueling operations. This scheduling problem consists of a fixed set of cruisers requiring aerial refueling at fixed locations at fixed points in time. The problem asks for an assignment of a (fixed or variable) number of tankers in order to conduct these operations while minimizing some objective function such as the fuel consumption of the tankers or the number of required tankers.

We formulate a combinatorial problem based on a simple model of the fuel consumption of the tankers, depending on the total weight as well as aerodynamic efficiency. We discuss several properties of the model, leading to an improved colum generation approach, and conduct computational experiments in order to study the effect on the overall fuel savings as well as the computational tractability of the scheduling problem.

■ MC-15

Monday, 12:30-14:00 - H2.32

Complementarity Problems, Variational Inequalities and Equilibrium

Stream: Mathematical Programming
Invited session
Chair: Viacheslav Kalashnikov

1 - A Riesz-Thorin type interpolation theorem in Euclidean Jordan algebras
Roman Sznajder

In a Euclidean Jordan algebra which carries a trace inner product, to each element we associate the eigenvalue vector whose components are the eigenvalues of this element written in the decreasing order. For any real number p not less than one we define the corresponding spectral norm of an element of the Euclidean Jordan algebra as the p-norm of its eigenvalue vector. In this paper, we prove a Riesz-Thorin type interpolation theorem.

2 - LCP based planning under uncertainty
Bogdan Gavrea

We present robust strategies to control and plan the motion of rigid body systems in the presence of uncertainties. Our approach is based on the analysis of the linear complementarity problems underlying the numerical integration schemes. We discuss applications of these strategies to autonomous navigation and manipulation of meso-scale rigid body systems. A quasi-static formulation is considered, but the scheme we propose can be easily used in a dynamic setting as well. When obstacle avoidance is required (autonomous navigation for example), virtual contacts can be enforced between safety rigid cages that encompass the elements in the scene. In our opinion, the geometry and dimensions of the safety cages can be trained in a neural network framework This may generate interesting solutions to traffic management problems.

3 - A Bilevel Optimal Control Approach to the Natural Gas Cash-Out Problem
Yosefat Nava-Alemán, Viacheslav Kalashnikov, Nataliya Kalashnykova

Bilevel programs are hierarchical optimization problems in the sense that their constraints are defined in part by a second parametric optimization problem. Hierarchical structures can be found in diverse scientific disciplines including environmental studies, classification theory, databases, network design, transportation, game theory, economics, and new applications, such as the gas cash-out problem. In its turn, this stimulates the development of both new theoretical results and efficient algorithms to solve bilevel programming problems. A particular bilevel approach technique can be exercised as applied to the optimal control problem arising in the natural gas industry.This problem has been formulated as a mixed-integer model seeking to minimize cash-out penalty costs imposed on a natural gas shipping company. In this talk, we formulate the gas cash-out problem as a bilevel optimal control problem (BOCP) where the upper level is equipped with a Mayer-type cost function and pure state constraints. Meanwhile, the lower level is formulated as a finite-dimensional mixed-integer programming problem (MIP) with only one binary variable. After specifying the model and describing the system's behavior, we reformulate it as a single-level problem, provide Pontryagin-type optimality conditions, and illustrate the theory by means of a small-dimensional example. Finally, we show the results of the application of the optimality conditions to the cash-out problem.

4 - On Consistent Conjectural Variations Equilibrium in the Oligopoly Model
José G. Flores-Muñiz, Viacheslav Kalashnikov, Nataliya Kalashnykova

According to the concept of conjectural variations equilibrium (CVE), the oligopoly agents behave as follows: each agent chooses his/her most favorable action taking into account that every rival's strategy is a conjectured function of his own strategy. The main obstacle in the way of admitting this concept is its consistency. The equilibrium is consistent if the conjectural best response of each agent coincides with his conjectured reaction function. However, such a definition doesn't work if the number of players is greater than two (since the coincidence is impossible). In order to cope with such a conceptual difficulty arising in many-player games, a completely new approach was proposed. Namely, one supposes that each player makes conjectures not about the optimal response functions of the other players but only about first-order variations of the market price depending upon his/her infinitesimal output variations. In the equilibrium, each agent applies a verification procedure and check if his influence coefficient is consistent with those of the rest of the agents. In a case when the CVE is consistent for each agent, we call it interior (in contrast to the exterior equilibrium, in which not all conjectures must be consistent with others). As in general, the consistent conjectures need not coincide with those of Nash, an interesting question arises: Is there any relationship between the classical Nash equilibrium and the CVE? The question is answered positively.

■ MC-16

Monday, 12:30-14:00 - Theatre A

Combinatorial-Continuous Hybrid Optimization and Control

Stream: Combinatorial Optimization II
Invited session
Chair: Gerhard-Wilhelm Weber

1 - A review and computational comparison of bound constrained mixed-integer derivative-free optimization algorithms
Nikolaos Ploskas, Nikolaos Sahinidis

A growing number of applications in science and engineering deal with the solution of black-box optimization problems, where derivative information of the objective function is unavailable, unreliable or impractical to obtain. The algorithms that are utilized to solve this type of problems are called derivative-free algorithms. Although the algorithmic and theoretical aspects of derivative-free algorithms have significantly progressed over the past two decade, derivative-free algorithms dealing with discrete variables have not yet attracted much attention. In this work, we review recent advances on solving bound-constrained mixed-integer derivative-free optimization problems and present a computational comparison of existing implementations on a large collection of test problems. Thirteen bound constrained mixed-integer derivative-free optimization solvers are compared using a test set of 188 problems. The test bed includes pure integer and mixed-integer problems. Computational results show that the ability of all these solvers to obtain good solutions diminishes with increasing problem size. Computational results show that there is no single solver whose performance dominates that of all others in all types of problems. We present the best solvers for each type of problems (pure integer or mixed integer problems; small, medium or large problems; problems with well-defined or missing bounds).

2 - Subquadratic Time Algorithms for Minsum k-Sink Problems on Dynamic Flow Path Networks
Yuya Higashikawa, Naoki Katoh, Junichi Teruyama

We address the facility location problems on dynamic flow path networks. A dynamic path network consists of an undirected path with positive edge lengths, positive edge capacities, and positive vertex supplies. A path can be considered as a road, an edge length as the distance along a road segment and a vertex supply as the number of people at a location. An edge capacity limits the number of people that can enter the edge in a unit of time. The problem is to find the location of facilities on a dynamic flow path network in such a way that the aggregate evacuation time to them is minimized. Also, we consider another model of the problem restricted so that all the people at a vertex have to evacuate to the same facility, known as the confluent flow model. For both the models, we develop first subquadratic time algorithms, which improve upon the previous result for the confluent flow model by Benkoczi et al., IWOCA2018.

3 - A MILP model for multifluid microgrid management
Slawomir Pietrasz, Lilia Bouchendouka

Existing work around the microgrid concept mostly focuses on the electrical network. In this work, we propose an energy management system (EMS) solution for a small-scale multi-fluid microgrid which operates in islanded mode. Our microgrid combines a wide range of technologies covering controllable generation units (diesel generators and fuel cells), uncontrollable sources (photovoltaic panels and wind turbines), energy storage devices (battery energy storage systems, hydrogen tanks) and two types of demand: electrical (residential load, electrolyzer, fuel cell) and hydrogen (Fuel Cell Electric Vehicle). The multi-fluid microgrid energy management problem is formulated as a Mixed Integer Linear Programme (MILP). The objective is to satisfy the demand in electricity and hydrogen at a minimum financial cost, while enhancing the flexibility in terms of power supply. Wired to weather feeds, a climatic statistical model predicts renewable power generation and local load curves one day ahead. Physical operating constraints have been linearized and the mutliperiod optimization problem is efficiently solved by commercial solvers. Our algorithm has been tested on a multi-fluid microgrid demonstration platform to illustrate the relevance of the solution and to verify its feasibility. Efficient interactions between electricity, hydrogen and transportation networks allows a day-ahead energy production planning with reduced operating costs.

4 - FIFO discipline among dispatchers in hazmat routing-scheduling
Reza Zanjirani Farahani, Seyed Sina Mohri, Nasrin Asgari, Michael Bourlakis

This research investigates a hazmat routing-scheduling problem for a transportation company in an urban transportation network. The problem considers multiple hazmat classes when incident probabilities are unknown due to lack of sufficient historical data or accuracy. Since the various vehicles take different routes and schedules to avoid multiple accidents on the same link to minimize overall loss, the company will face two issues in practice: (1) unfairly, there is no guarantee that the vehicle departing earlier from the origin, arrive the destinations earlier (FIFO); (2) the focus on the minimization of loss increases travel time. We suggest a linked-based formulation to address these issues. Our bi-objective model (i) observes FIFO discipline and (ii) considers two objective functions to study trade-off between loss and travel time objectives. By applying queuing on waiting links, the problem is formulated through demon approach and a combination of Nash and Stackelberg games. We have developed a hybrid heuristics algorithm to solve this operational problem efficiently. Verification of the model, validation and tuning of the developed algorithm are accomplished via small, medium and large size test problems. The tuned heuristic technique is run on data from a real-life case. Sensitivity analysis on the case study provides some insights for the practitioners regarding trade-offs between risk and travel time and impact of FIFO on them.

■ MC-17
Monday, 12:30-14:00 - A005

Stochastic Models in Manufacturing

Stream: Stochastic Models and Queueing
Invited session
Chair: Pedro Henrique Sousa

1 - Optimal Control of Production/Inventory Systems with Correlated Demand Inter-Arrival and Processing Times
Nima Manafzadeh Dizbin, Baris Tan

We consider the production control problem of a production/inventory system with correlated demand inter-arrival and processing times modeled as Markovian Arrival Processes. The control problem is minimizing the expected average cost of the system in the steady-state by controlling when to produce an available part. We prove that the optimal control policy is a state-dependent base-stock policy. We determine the optimal threshold levels of the system controlled by the state-dependent base-stock policy by using a Matrix Geometric method. We then investigate how the autocorrelation of the arrival and service processes impact the optimal threshold levels of the system. Finally, we compare the performance of the optimal policy with of a single-threshold base-stock policy where the threshold level is set independent of the state of the system. Our numerical analysis demonstrates that the state-independent base-stock policy performs quite well for negatively correlated processes. However, when the processes are positively correlated, using a state-dependent base-stock policy improves the performance of the system.

2 - Capacity decisions in MTO production systems with time-dependent demand
Jannik Vogel, Raik Stolletz

With increasing importance of customized and fully personalized products, the planning of MTO production systems becomes more relevant. Manufacturers with MTO production can cope with variability in the demand by adjustments of the machine speed which lead to additional cost. We investigate how to decide on the processing rate in a single stage MTO production system modeled as an M(t)/M(t)/1-queueing system. The objective is to maximize the reward for finished products diminished by holding cost for the work-in-process and service cost proportional to the processing rate.

We discuss structural insights for stationary systems. For the time-dependent system, we present a deterministic fluid approach and a stochastic stationary-backlog carryover approach in order to optimize the time-dependent system. A numerical study shows the structure of the time-dependent solution under realistic assumptions. In addition, the reliability of the optimization approaches is analyzed.

3 - Warranty policy with imperfect preventive maintenance for repairable items
Minjae Park

In this paper, we develop a cost model under two-dimensional warranty with age and usage based on Lemon Law and determine decision variables such as optimal preventive maintenance cycle for age and usage perspectives and optimal length of warranty period. We propose a two-dimensional maintenance strategy, under which the item is preventively maintained according to a specified age interval or usage interval, whichever occurs first. A periodic preventive maintenance service is considered which can be implemented to reduce the repair cost of a repairable product under warranty. The optimization of imperfect preventive maintenance for repairable items is investigated from the manufacturer's perspective by taking into account the moments of customers purchasing two-dimensional warranty. During the warranty period, preventive maintenance service and refund service is conducted to reduce the degradation rate which the product is in operation and to increase customers' satisfaction. We consider minimal repair service, refund service, preventive maintenance service for the warranty services. The numerical application is implemented using the proposed approach and examples are discussed to exemplify the applicability of the methodologies derived in this paper.

4 - Markov decision process and simulation applied to well campaign resource estimation
Pedro Henrique Sousa

Oil exploration processes are complex and can be classified as capital-intensive business. The investments are primary designated to service and material procurement. In addition, oil and gas exploration carry intensive uncertainties levels that should be buffered in order to minimize profit lost. The decision maker is then faced with the challenge of performing these activities as economically as possible without compromising the efficiency. To guide the decisions, focused on critical resources procurement, this work proposes the use of Markov Decision Processes (MDP) optimal policy to perform a complete set of simulations. The resulting model was tested for a 250-day exploration plan comprising three and five wells campaign. The model converges rather rapidly and the optimal policy and the simulation process allows the estimation of the required number of critical resources.

■ MC-18

Monday, 12:30-14:00 - C112

Optimization Based Ensemble Selections Methods

Stream: Multiple Classifier Systems and Their Applications
Invited session
Chair: *Sureyya Ozogur-Akyuz*
Chair: *Sureyya Ozogur-Akyuz*

1 - Post-Separation Classifier Feature Reduction
John Chinneck

Feature reduction tries to find the smallest set of features that allows acceptable separation of the data. This is time-consuming, e.g. wrapper methods require multiple solutions using different subsets of the features. We present a new approach: (i) find a separating hyperplane by any method using all features, then (ii) find a different hyperplane that provides the same separation while using fewer features. The novelty is in the second step, which is based on new heuristics for finding sparse solutions to linear programs. Finding a separating hyperplane can be cast as an instance of the Maximum Feasible Subset problem (maxFS): given an infeasible set of linear constraints, find the largest cardinality feasible subset. There are good heuristics for this NP-hard problem. To convert: transform each data point into a linear inequality in variables representing the feature weights, then apply a maxFS heuristic to find a solution that satisfies as many of the inequalities as possible (i.e. correctly classifies as many of the data points as possible). We adapt this formulation for use with any hyperplane placement method: (i) find the hyperplane, (ii) convert only the correctly classified points to inequalities, (iii) find a sparse solution (i.e. one in which few variables are nonzero) to this feasible system. Few nonzero variables is the same as few features. The sparse solution algorithm is itself another variant of a maxFS solution heuristic. Experimental results are given.

2 - Ensemble Feature Selection by Accuracy Diversity Trade off
Sureyya Ozogur-Akyuz, Pinar Karadayi Atas

Feature selection and Ensemble learning are new research topics in machine learning recently. Ensemble learning improves performance of machine learning methods by combining several models. This approach allows the production of better predictive performance compared to a single model. In recent years, a new type of feature selection method, called ensemble feature selection, has been proposed and studied. In this new method, multiple diverse feature selection method results are combined. In many ways, this approach is superior to traditional feature selection methods of choice. In this paper, we propose a novel ensemble pruning algorithm specifically on feature selection methods by selecting the best subset of the ensemble having both accurate and diverse models via optimization theory. The proposed ensemble feature selection algorithm is compared with existing feature selection algorithms on several datasets. The performance results shows that the proposed algorithm in this study gives better predictions.

3 - Novel Ensemble SVM Algorithm for Classification of Motor Imagery Task
Duygu Ucuncu, Muhammad Ammar Ali, Pinar Karadayi Atas, Sureyya Ozogur-Akyuz

Brain-Computer Interface (BCI) helps to communicate for the disabled and handicapped in which Electroencephalogram (EEG) based approaches are used for Motor Imagery (MI) tasks. EEG signals are well-known for being non-stationary and are sensitive to artifacts from various sources such as the physical and mental state of the patient, their mood, their posture, and any external noise or distractions etc. Processing of this type of data directly affects the classification performance which leads a critical step in any BCI system. Ensemble learning has been used for various BCI classification problems including MI and P300 event related potential which has been shown to be robust. The purpose of this paper is to develop an algorithm which uses ensemble selection for EEG classification evoked by an MI task. In order to achieve this, the features of an EEG dataset are extracted and trained by a range of Support Vector Machines (SVMs) to make a diverse ensemble of classifiers. This ensemble is then pruned by using a novel optimization model by a Difference of Convex Algorithm (DCA) which has not been used on EEG data before.

4 - Data Management System with Graphical User Interface for Multi-Group Classification
Fatih Rahim, Metin Türkay

Multi-class data classification is a supervised machine learning problem that involves assigning data to multiple groups. We present a data management system with graphical user interface to manage the large value of complex statistical information hidden in the classification data sets. The system is founded on the notion of linear separability. The core of the approach involves splitting each class's dataset into subsets such that the subsets of different classes are linearly separable. The subsets are generated via an MILP model that minimizes weighted sum of the number of subsets and the misclassified samples. For the datasets that cannot be handled by the model, we resort to an MILP-based algorithm. We build classifiers based on the convex hulls of the subsets and the polyhedral regions for the testing phase. The LP, QP and MILP models are solved using Gurobi Optimizer. The system supports setting the necessary parameters of the model and the algorithm such as, the number of subsets allowed per class, the maximum number of iterations, time limits for the MILP models, etc. In addition, it allows the solution of the algorithm to be used as starting solution for the main model. For the validation of the algorithm, 10-Fold CV, LOOCV, train test set pairs and percent split are supported by the system. Percent accuracy levels, and confusion matrices are reported in addition to the computation time.

■ MC-19

Monday, 12:30-14:00 - C115

Knowledge Analytics Applications I

Stream: Knowledge and Knowledge Analytics
Invited session
Chair: *A. D. Amar*

1 - Inverse Problem Specification for Resource-constrained Devices
Kiyoshi Yoneda, Charles Childers, Walter Celaschi

This is an attempt to bring the inverse problem approach to autonomous machines under resource-constrained computing devices.

The workflow starts by describing a system of overdetermined equations relating a decision vector to an outcome vector of higher dimension. The objective function is specified not directly as a mathematical expression but through a set of tables with the amount of item in concern against its utility.

The utility is measured in terms of action worth probability to endow behavioral semantics. The utility tables thus obtained are converted into tables of pairs consisting of the amount of item in concern and its standardized value. For each item a standardization function is defined by linearly interpolating this table.

This results in reduction of the inverse problem into optimization in the same way as the method of least squares, with piecewise linear rather than linear standardization functions. The optimization has to be carried out derivative-free since the linear interpolation turns the loss function nondifferentiable.

A minimal computer language of the Forth family is proposed for an implementation providing portability among devices of varied architectures. Techniques to deal with limited resources will be touched upon.

2 - Quantitative Compliance as a Driver for Automation in Container Terminals

Leif Meier

Compliance management covers all efforts to comply with regulations such as laws and rules, policies, standards and/or even ethics.

Automated processes are dealing with a huge number of (trans-) actions to be executed in short term, depending on big data sets. Each single transaction that is executed must comply with above regulations.

Quantitative Compliance (QC) operates with applied methods from Operations Research and Econometrics to manage processes and risks in complex systems considering regulations to improve decisions from available information.

We show results of a QC-case study from automated Container Terminals to identify suspicious data constellations and anomalies from multiple sources in order to provide help to correct data sets before having an impact on the operations process, e.g. causing a crane stop or system breakdown.

3 - Comparison of Rotation Criteria of Factor Analysis and Independent Component Analysis

Yuto Imamura, Takahiro Nishigaki, Takashi Onoda

The purpose of this research is to clarify the difference of the characteristics of independent component analysis and factor analysis. We focus on the rotation criterion of these two methods this paper. Previous research derived the relation between the orthomax rotation criterion used in factor analysis and kurtosis rotation criterion used in independent component analysis. This research discovered that the kurtosis criterion is the orthomax criterion that is changed weight. Previous research doesn't address the difference between kurtosis and other factor rotation criterion, and characteristics of kurtosis. We derived the relationship between Crawford and Ferguson rotation criterion that is used in factor analysis and kurtosis rotation criterion. Moreover, we discovered that the characteristics of kurtosis criterion that emphasizes the simplification of rows of a factor loading matrix because the relationship between Crawford and Ferguson criterion and kurtosis criterion. Experimental result using sample data showed the characteristics of kurtosis we discovered. We discovered that Crawford and Ferguson criterion is equivalent to kurtosis criterion by changing weights. In this research, we analyzed characteristics of kurtosis criterion and relationship of Crawford and Ferguson criterion and kurtosis criterion. The remaining problem is more detail difference of independent component analysis and factor analysis.

4 - Wiki Corpus-based Vocabulary Level Dictionary by Text Mining Methods

Megumi Yamamoto, Nobuo Umemura, Hiroyuki Kawano

The authors are interested in advanced applications by text mining technology. In this presentation, we propose a construction method of a vocabulary level dictionary based on word frequency from the Japanese Wikipedia dataset as a large-scale corpus. We try to apply LDA (Latent Dirichlet Allocation) to Wiki corpus in order to generate topics based on word frequency, but computing cost of the difficulty index of rarely appearing words is very expensive. Therefore, we propose a combined method with the word difficulty index by TF-IDF (Term Frequency - Inverse Document Frequency) as a conventional method, and attempt to construct a highly comprehensive and accurate vocabulary level dictionary. In order to evaluate the practicality of the constructed vocabulary level dictionary, we introduce it to the educational automated essay scoring support system using SVM (Support Vector Machine), which has been developed in our previous researches. By using our vocabulary level dictionary, we confirm the sufficient evaluation of vocabulary level for writing essays by university students. Furthermore, we evaluate the accuracy compared with teacher's score. In our experiments, the extent to which the scoring accuracy of the automated essay scoring changes when using the vocabulary level dictionary for conventional Japanese learners and when using the vocabulary level dictionary constructed by our proposed method.

■ MC-20

Monday, 12:30-14:00 - C006

Sustainable Urban Logistics

Stream: Environmental Sustainability in Supply Chains
Invited session
Chair: Alexandra Anderluh

1 - Dynamic solutions for electric scooters collection problem

Belma Turan

As European cities move towards developing green and sustainable urban centers, the arrival of electric vehicles has expanded. Since September 2018 several companies offer e-scooters in the city of Vienna and advertise them as an efficient and eco-friendly way of transportation in cities and urban areas. The scooters can be rented throughout the day; during the night they are collected and charged, and in the morning distributed to designated pickup locations. The collection of the scooters in the evening needs careful planning, as, due to the long charging times, only a limited time window is left for the pickup. This turned out to be more challenging task than originally anticipated: Although the geo-positions of the scooters can be tracked via mobile app, the exact position might vary up to several dozen meters from the position shown in the app. As this happens quite often, the initial planning might result in sub-optimal solutions, as, due to delays, the scooters will arrive late in the depot and might not be ready for the morning distribution. Therefore, we propose a dynamic solution method, where, after every 20 minutes, the actual positions of drivers are observed and, if needed, the problem is re-optimized. In this way the fleet can be better utilized and necessary actions can be taken in order to avoid delays, e.g. employing an additional driver. The benefit of the re-optimization is measured by evaluating the additional costs and lost sales caused by delays.

2 - A user-centered approach for the multimodal car- and ride-sharing problem (MMCRP)

Miriam Enzi, Sophie Parragh, Jakob Puchinger

In the multimodal car and ride sharing problem (MMCRP) we aim at determining the optimal mode of transport (MOT)-assignment for travel requests and to schedule the tours of available cars. A tour corresponds to a route of a car during one day, encompassing one or more drivers, handing over the vehicle at a depot, and including possible ride-sharing activities. Ride-sharing is allowed even if drivers and riders do not share the same origin and/or destination. The number of cars at depots is limited and all other MOTs have unlimited capacity.

We investigate the MMCRP from a user-centered point of view. User satisfaction is a crucial aspect in shared mobility systems, we therefore consider user preferences in an alternate objective. Users may choose and rank their preferred modes of transport for different times of the day. In this way we account for e.g. different traffic conditions throughout the planning horizon and opt to maximize user satisfaction. We present a general heuristic solution framework where we iteratively build vehicle tours and enhance the incumbent solution by varying the MOT-assignment as well as adding possible ride-sharing candidates to the drivers. We analyze the impact of including a user perspective to the optimization problem and compare the new objective function to results obtained by minimizing costs. Computational experiments based on realistic instances are reported.

3 - Innovative approaches for supporting sustainable and reliable planning of rail and intermodal transport

Martin Hrusovsky, Emrah Demir, Werner Jammernegg, Tina Wakolbinger, Tom van Woensel

Changing customer preferences and innovative logistics concepts (e.g., physical internet) lead to smaller batch sizes, higher transport volumes and shorter delivery times, resulting in new challenges for transport operations. Consequently, road transport is dominating transport mode due to its high flexibility and adaptability to these changes. However, increasing road traffic negatively impacts the environment and increases the risk of disruptions, thus affecting transport reliability. Therefore alternative transport modes, such as rail or intermodal transport, can be used to reduce these negative impacts. However, these alternatives require efficient planning approaches in order to increase their flexibility and responsiveness. In this talk, we present two planning approaches dealing with efficient planning of rail and intermodal transport operations. In the first case, a simulation-optimization model is used for operational intermodal transport planning. This model combines economic and environmental criteria for optimizing the routes and increases the reliability by including disruptions. To this end, potential disruptions are considered in offline planning whereas several policies are compared in online planning where a fast reaction to an occurred disruption is necessary. The second case presents a planning approach for rail wagon fleets that should contribute to shorter lead times and less empty miles by anticipating future transport demand and possible disruptions.

4 - Evaluating measures for sustainable urban freight transport - A case study in Vienna

Alexandra Anderluh, Tina Wakolbinger

Continuously increasing freight traffic volumes, which negatively impact the quality of life of citizens as well as the economic efficiency of companies due to noise and congestion, are a typical characteristic of today's cities. Urban road haulage - currently conducted to a large extent by fossil-fueled vehicles - causes large amounts of greenhouse gas emissions which result in negative climate effects. Within the framework of urban logistics, it is therefore essential to adopt suitable measures in urban freight transport, which enable a reduction in emissions while ensuring high-quality but also economic supply and disposal for a city. In our work, the basis is an origin-destination-model of freight traffic flows of selected sectors. On the one hand, the model builds on traffic data from the City of Vienna and the Asfinag, and on data provided by selected companies from 5 sectors (CEP, construction site traffic, food, non-food consumer goods and waste disposal). Based on this model, specific measures (shift to low emission/non-emission vehicles, multimodal transport, and usage of consolidation centers) can be evaluated for their suitability with regard to emission reduction, quality of supply/disposal and economic efficiency. Finally, the selected measures are evaluated for a specific company and its freight transport scheme in Vienna. Thus, the results of our work can serve affected stakeholder groups as decision support in urban transport policy.

■ MC-21

Monday, 12:30-14:00 - F101

Lot Sizing I

Stream: Lot Sizing, Lot Scheduling and Production Planning

Invited session

Chair: *Céline Gicquel*

1 - The Profit-Maximizing Lot Size Problem with Pricing Lag Effects

Erik Langelo, Bård-Inge Pettersen, Per Kristian Rekdal

In 1970, Joseph Thomas extended the well-known dynamic lot size model of Wagner and Whitin to include variable prices, as well as variable production costs. This master thesis extends Thomas' model to include something called the "lag effect".

Formally, this master thesis models a disaggregated, finite-horizon, profit-maximizing dynamic lot size problem with pricing lag effects in demand. This effect models the tendency for customers to stock up on a product when it is offered for cheap, causing demand to increase in the "cheap" time period, while it decreases in the next. In effect, lowering the price causes demand to shift backwards in time, in addition to increasing demand as in most demand functions.

The problem is to decide in which time periods to produce, how much to produce in each period, and which price to set in each period. The objective is to maximize the total profit, defined as total revenue minus total setup cost, production cost and inventory holding cost.

Three theorems which restrict the amount of possible optimal solutions are proved. A solution is then provided to the production horizon problem, a sub-problem of the main problem. The production horizon problem is then solved with two different models: with and without the lag effect. The optimal solutions of these models are then compared for varying values of some key parameters.

2 - Economic Lot Sizing Problem with Inventory Dependent Demand

Mehmet Onal

We consider an economic lot sizing problem where the demand in a period is a piece-wise linear and concave function of the amount of the available inventory (after production) in that period. First we state our assumptions on the demand function and highlight its properties. Then we show that the problem is NP-hard even when there are time invariant production capacities. We then state some properties of optimal solutions and propose a polynomial time algorithm when there are no capacity restrictions on production. Finally, we discuss some future research opportunities.

3 - A decentralized spillover effect algorithm for the capacitated lot-sizing problem with back-orders

Marin Lujak, Eva Onaindia, Alberto Fernandez

In this paper, we study single-level multiple-item capacitated lot-sizing problem with backorders (CLSP-BO) present in production planning and supply chain management and extensible to many other areas. The CLSP-BO is a special kind of the CLSP problem as production can be anticipated or delayed in respect to the product demands, resulting in holding and backlog costs, respectively. It is crucial in cases with a too high demand, since, otherwise, no feasible plan would exist. Some Lagrangean relaxation-based approaches exist for this NP-hard problem but they are mostly centralized and intractable. Aiming at decision distribution, scalability, and low computational complexity, we propose a decentralized, asynchronous, and iterative heuristic algorithm based on the spillover effect. In economy, the spillover effect is related to the interconnection of economies of different countries. In ecology, it refers to the moment when the available resources in one habitat cannot support the entire insect population, producing an "overflow", flooding adjacent habitats. For each positive demand of every item at each period, the proposed spillover algorithm assigns iteratively limited resources based on the ordering of accumulated costs of all demands for each period and then balances the usage of resources among individual periods based on the spillover effect. We show the functioning of the proposed algorithm on some examples and compare it with relevant benchmark approaches.

4 - Production planning with on-site generation of renewable energy
Céline Gicquel, Ayse Akbalik, Bernard Penz, Christophe Rapine

Many industrial companies now use some type of on-site generated renewable energy to provide power to their facilities. However, due to the high variability in its availability, renewable energy is not expected to fully replace grid electricity but rather to be used in combination with it.

We investigate a single-item single-resource mid-term production planning problem. In our model, the production resource has a stationary default nominal capacity which can be temporarily increased by installing some extra capacity. This extra capacity is a multiple of a base capacity extension value and a fixed cost has to be paid each time one unit of this base capacity extension value is installed. Production and inventory holding costs are assumed to be linear. The production activities in the factory translate into an energy demand. We consider that two alternative sources of energy are available to supply this demand: an on-site generated renewable energy, free of use but available in a limited time-varying quantity, and the grid power, available at any required level but by paying a unit cost per kWh purchased.

We show that this problem is NP-complete, even in the case where a single capacity extension is allowed. For the special case where the on-site generated renewable energy is not enough to produce at the default nominal capacity, we provide a polynomial time algorithm based on the resolution of a sequence of Discrete Lot-Sizing Problems.

■ MC-22

Monday, 12:30-14:00 - F102

Simulation in Manufacturing Operations

Stream: Production Planning and Control for Complex Manufacturing Systems
Invited session
Chair: *Christoph Laroque*

1 - Applying Resource Constrained Programming in the Planning Process of Agricultural Contractors
David Wittwer

Compared to other industries agricultural products have a very high proportion of logistics costs between 40 to 50% of their total costs. The increased focus on core competences in all industries has led to highly specialized farmers that outsource their logistics efforts to agricultural contractors. These contractors face a complex planning problem in order to maintain profitability and competitiveness which is commonly solved via instinct. High costs and the current inefficient approach lead to the assumption of big optimization potential in this field. The agricultural environment entails several special constraints due to specialized machinery used for the harvesting process, unbalanced order loads despite a long planning period and peaks during harvest season with high weather dependencies. This study explores and describes the influencing factors and describes the logistic process chains considering technological constraints. These restrictions are the basis to develop a mathematical model of the optimization problem.

2 - The impact of supply chain design options on performance measures in the semiconductor industry
Bernhard Oberegger, Andreas Felsberger, Boualem Rabta, Gerald Reiner

We analyse a semiconductor supply chain facing stochastic demand and uncertainties in lead-times. A semiconductor supply chain typically consists of several stages such as frontend production, backend production and distribution centres (DCs). A common strategy in this high-volume supply network is to maintain a significant inventory of products (called die-bank), between the frontend production and backend assembly stages. Since most customisation takes place in assembly and final test, this approach allows wafers to be pulled from the die-bank and processed rapidly through final test for delivery, avoiding the long cycle times of the frontend wafer fabs. However, this leads to increased complexity in addition to the uncertainties in demand and lead-times, e.g. make-to-stock vs. make-to-order or assembly-to-order processes. The objective is to determine the best strategy in terms of inventory positioning and DCs localisations in the network in a way that the amount of the inventory (safety stock) and transport costs are minimized. We build a simulation model for the semiconductor supply chain under study. We compare different network configurations such as centralised and decentralised distribution centres by considering the impact on operational performance measures such as services levels, lead-time and WIP.

■ MC-23

Monday, 12:30-14:00 - F103

Retail Marketing

Stream: Demand and Supply Management in Retail and Consumer Goods
Invited session
Chair: *Arnd Huchzermeier*
Chair: *Nishant Kumar Verma*

1 - Discount allocation optimisation considering customer relevancy scores.
Nishant Kumar Verma, Milan Kumar

This paper deals with optimal allocation of limited discounts/coupons to potential customers. We consider a product company who wants to reward its loyal customers by giving them heavy discount on the products they buy repeatedly. The company already has "Relevancy scores" for its customers which signifies the probability of buying these products in their next visit. Based on the scores company wants to allocate most relevant set of product discounts to customers. We develop a mixed integer non linear programming (MINLP) model with constraints to come up with the optimal discount allocation. With the help of real time company data, we conduct extensive numerical analysis to understand the allocation process. Existing papers in the extant literature talk about various scoring models to assess their customers based on their individual buying history. This paper attempts to study the optimum discount allocation policy using normative mathematical model along with real time data from one of the leading customer product companies.

2 - Optimal replenishment and disposal policy for substitutable products with fixed shelf life
Konstantina Skouri, Iris-Pandora Krommyda, Vasileios Tatsis

The optimal replenishment policy for two products, with a fixed shelf life, that are ordered simultaneously from the same supplier is studied. When the products are near their expiration date the retailer offers a discount on their price in order to increase demand. However, the demand also becomes a decreasing function with respect to the time remaining before the expiration date as the customers become aware of the expiration date of the products. In order to avoid waste, unsold items at the end of the replenishment cycle can be donated to non-profit organizations or be sold at a salvage price to a secondary market. We also assume that in case of a stock-out for one of the products, a known fraction of its demand can be satisfied by using the stock of the other product. The aim is to determine the optimal reorder interval, the time instant to discount each product's initial selling price and the quantity of each product that should be donated or sold to the secondary market so that the retailer's profit is maximized. Numerical examples are conducted in order to examine the influence of different system parameters to the optimal policy.

3 - Optimal values of policy parameters for competing retailers under disruption risk and price constraints
Milan Kumar, Preetam Basu, Balram Avittathur

Price gouging is the practice of raising prices more than what is needed to cover increased cost for bringing extra supplies during an event of a disruption. During two separate occasions in 2014, namely, New Year's Eve and hurricane Sandy; Uber charged as much as 4.5 times higher than their regular fare. The regulators intervened, and Uber agreed to cap the surge pricing at 2.5 times the normal price during 'abnormal disruptions of the market.' Price fluctuation is a common phenomenon these days. Firms source their products from suppliers in multiple countries thus exposing the supply chain to vulnerabilities. When supply of a product is affected due to disruption at one or more node in a supply chain, it results in lack of supplies in the market which may lead to increase in prices of the good.

In this paper, we explore two questions: 1. how to analyse the price constraints from the perspective of social surplus and 2. what form of price constraint can be used for a market that is characterised by market-share of the retailers, cost of production/procurement and consumer price sensitivity? We look at two competing retailers competing in end-market and offering a partially substitutable product. One of the retailers is exposed to supply risk. Retailers increase prices in the face of supply disruption. The regulators with information about the supply risk can choose between the price constraints and the parameter that will dictate the level of constraint.

■ MC-24

Monday, 12:30-14:00 - F103A

Stochastic modeling for service systems

Stream: Supply Chain Management
Invited session
Chair: *Benjamin Legros*

1 - Late rejection, a strategy for overflow management
Benjamin Legros, Oualid Jouini

Motivated by overflow policies implemented for inventory management and in contact centers, we consider a multi-server queue where a rejection control is exercised on customers who are currently waiting in the queue. Our objective is to find a good balance between conflicting objectives, namely, the rate of rejected customers and a waiting cost function which may involve percentiles of the waiting time. We develop a Markov decision process approach where the waiting time of the first customer in line is used in a discretized form to define the system state. We show that a time-based threshold policy is optimal and we develop a procedure to compute the optimal threshold. Our analysis explains some known behaviors in practice. For instance, if the wait cost function is only constituted of percentiles of the waiting time, then the optimal threshold is one of the time limits defining the percentiles.

Next, we analyze the transient behavior and the busy period of the corresponding Markovian queue with deterministic rejection. We obtain the Laplace Transform of the transient probabilities of the approximated model in closed-form. This allows us to compute the explicit expressions of the Laplace transform of the main performance measures for the real system. One interesting insight of this analysis is that the full busy period of the unstable M/M/s queue may have a finite coefficient of variation.

2 - Optimal Contact Center Staffing and Scheduling with Machine Learning
Ger Koole, Qingchen Wang, Siqiao Li

We consider making weekly schedules in a multi-channel multi-skill call center. The only known accurate solution method is simulation optimization, but this tends to be slow and therefore leading to highly suboptimal solutions. To speed up this process we approximate the performance by a predictive model based on a limited set of simulations and optimize using this approximation. We present numerical results from a real call center.

3 - An inventory model for items with time-price-advertisement-dependent demand
Joaquin Sicilia-Rodriguez, Luis A. San-José-Nieto, Beatriz Abdul-Jalbar

An inventory model for goods whose demands depend on time, price and advertising frequency is analyzed. The inventory system refers to a single product and it is assumed that the planning horizon is infinite. The profit during the inventory cycle is calculated as the difference between the revenue obtained from sales and the sum of the costs related to the inventory management. The objective consists of determining the selling price, the frequency of advertisement and the inventory cycle to maximize the average profit per unit time. An approach to solve this inventory problem is developed, which analyzes the properties of the objective function and presents an algorithmic procedure to obtain the optimal inventory policy. Some numerical examples are provided to illustrate how the optimal inventory policies are determined.

■ MC-25

Monday, 12:30-14:00 - F104

Cutting and Packing 3

Stream: Cutting and Packing
Invited session
Chair: *Antonio Martinez-sykora*
Chair: *Mateus Martin*

1 - A heuristic method for a 3D packing problem with applications to truck loading
Andrea Bettinelli, Matteo Pozzi, Daniele Vigo

We present a real-world application in which a three-dimensional bin-packing problem is solved in order to minimize the shipping cost of a given set of orders. The problem is addressed from the point of view of the shipper. It combines truck-loading constraints (such as weight balance, cargo stability, stacking rules), to ensure the feasibility of the loading pattern, with operational constraints related to the management of the orders (such as assignment of orders to carries, availability and due dates). In addition, it requires an accurate modelling of the cost tariffs. To solve the problem we propose a metaheuristic method based on the ruin-and-recreate paradigm. It features several constructive procedures leveraging on the concept of extreme point introduced by Crainic et al. (2008), and specialized procedures for recovering weight balance feasibility. The effectiveness of the approach is evaluated by testing real-world instances as well as benchmark instances form the literature.

2 - The multiperiod cutting stock problem: a biobjective approach
Kelly Cristina Poldi, Livia Pierini

The Cutting Stock Problem (CSP) arises when the cutting process optimization is requested and determines how larger objects must be cut into smaller items in order to meet the demand and satisfy some optimization criteria. The CSP that aims to minimize conflicting objectives can be characterized as a multiobjective problem. Considering the problem as a multiobjective means contemplate the preference relationship with optimization, giving the decision-maker the available alternatives for a more informed, comprehensive and safe choice. Two widely used techniques in multiobjective optimization are known as

Weighted Sum and E-constraint methods. Against the importance of the multiobjective approach and the lack of work adressing the Biobjective Multiperiod Cutting Stock Problem (BMCSP) that seeks to minimize the cost of production associated with the total length of cut objects (waste) and the inventory costs of objects and items, the objective of this study is to investigate the trade-off between the two conflicting objectives of the BMCSP and to compare the performance of the Weighted Sum and the E-constraint methods in obtaining the Pareto Front. Computational tests were performed in which the Column Generation method was used. The results confirmed a strong negative correlation between the objective functions of the model. A greater number of eficient solutions was obtained by the E-constraint method.

3 - The constrained two-dimensional guillotine cutting problem with defects: an ILP formulation, a Benders decomposition and a CP-based algorithm
Mateus Martin, Pedro Hokama, Reinaldo Morabito, Pedro Munari

This paper addresses a variant of two-dimensional cutting problems in which rectangular small pieces are obtained by cutting a rectangular object through guillotine cuts. The characteristics of this variant are: (i) the object contains some defects, and the items cut must be defective-free; (ii) there is an upper bound on the number of times an item type may appear in the cutting pattern; (iii) the number of guillotine stages is not restricted. This problem commonly arises in industrial settings that deal with defective materials, e.g., either by intrinsic characteristics of the object as in the cutting of wooden boards with knotholes in the wood industry, or by the manufacturing process as in the production of flat glass in the glass industry. Despite its potential applicability, few studies in the literature have addressed cutting problems with defective materials. We propose an integer linear programming (ILP) model for this problem based on the discretization of the defective object. As solution methods for the problem, we develop a Benders decomposition algorithm and a constraint-programming (CP) based algorithm. We evaluate these approaches through computational experiments, using benchmark instances from the literature. The results show that the methods are effective on different types of instances and can find optimal solutions even for instances with dimensions close to real-size.

■ MC-26

Monday, 12:30-14:00 - F106

Service Operations I

Stream: Service Operations Management
Invited session
Chair: *Oualid Jouini*
Chair: *Dongyuan Zhan*

1 - Using mixed integer linear programming to solve a real assignment problem in the service-to-business domain, considering levels of dependence between planning horizons
Minh-Phuoc Doan, Julien Fondrevelle, Valérie Botta-genoulaz, Jose Ribeiro

In this article we use a mixed integer linear programming (MILP) approach to solve a real agent assignment problem in the service-to-business domain. This problem is found in a Brazilian subcontracting company providing on-site services (cleaning, concierge and surveillance) to business clients. Each agent of the service company, having a contract type with daily and weekly work capacities, has to travel to clients' workplaces to provide services. Each service is characterized by a number of required agents, a daily start time, a daily end time, and its weekly repetitiveness. Solving this problem, the service company has two main objectives to reach including minimizing the total travel costs of its agents from their homes to the workplaces, and maximizing their satisfaction by balancing the workload between them. Because the demands of clients are weekly repeated and the work timetables of most of the agent contract types are defined per week, we choose to solve this problem over one-week planning horizons. The solutions obtained in each individual horizon are studied in three different scenarios corresponding to three levels of dependence between consecutive horizons (independent, fully dependent and dependent with buffer zones). The numerical experiments on the real data provided by the Brazilian company allow us to see the impact of these levels on the problem solution, thus, provide management tools for the company managers to improve their current assignment

2 - Spare Parts Planning for Manufacturing Systems with Buffer Storage
Julia Zimmermann, Gudrun Kiesmuller

The aim of spare parts planning for machines is to ensure high availability, such that the impact of failures on the production process can be reduced. Thus, spare parts can be used for preventive maintenance activities in order to avoid failures or for corrective maintenance after machines have failed. Then, parts are kept in stock to enable a fast repair by a replacement of a broken component. Further complexity appears if machines are arranged in series with intermediate buffers. In this case, the downtime of a machine does not necessarily lead to production losses. Additionally, the buffer sizes and other machines in line affect the demand for spare parts if operation dependent failures are considered. For this case, existing approaches for spare parts planning from the literature cannot be applied. In this paper, a flow line with unreliable machines and different buffer designs, like inter stage buffers or a centrally shared buffer, is considered. Failures of machines are caused by critical components in these machines. In order to reduce downtimes of the machines, spare parts are kept in stock. The system is modeled by a continuous-time Markov Chain and we derive exact expressions for several performance measures. We analyze the influence of the buffer design on spare parts provisioning and show how optimal manufacturing systems are designed.

3 - Forecasting Airport Transfer Passenger Flow Using Real-Time Data and Machine Learning
Xiaojia Guo

Airports and airlines have been challenged to improve decision-making by producing accurate forecasts in real time. In collaboration with Heathrow airport, we develop a predictive system that generates quantile forecasts of transfer passengers' connection times. Sampling from the distribution of individual passengers' connection times, the system also produces quantile forecasts for the number of passengers arriving at the immigration and security areas. The predictive model developed is based on a regression tree combined with copula-based simulations. We generalize the tree method to predict complete distributions, moving beyond point forecasts. To derive insights from the tree, we introduce the concept of a stable tree that can be summarized by its key variables' splits. We identify seven key factors that impact passengers' connection times, dividing passengers into 16 passenger segments. We find that adding correlations among the connection times of passengers arriving on the same flight can improve the forecasts of arrivals at the immigration and security areas. When compared to several benchmarks, our model is shown to be more accurate in both point forecasting and quantile forecasting. Our predictive system can produce accurate forecasts, frequently, and in real-time. With these forecasts, an airport's operating team can make data-driven decisions, identify late connecting passengers and assist them to make their connections. The airport can also update its resourcing

4 - Net-Metered Distributed Renewable Energy: A Peril for Utilities?
Jayashankar Swaminathan, Nur Sunar

Our paper studies the implications of such "distributed renewable energy" for utility profits and social welfare under net metering that has sparked heated debates in practice. We prove that when the equilibrium wholesale price is sufficiently sensitive to the changes in the wholesale demand, there exists a critical market reliance level above which the net-metered distributed generation strictly improves the utility's expected profit. Our analysis also suggests that under certain conditions, it can be favorable for utilities to motivate their customers to adopt distributed renewable energy technology as increased adoption strictly improves the utility profitability.

■ MC-27

Monday, 12:30-14:00 - F107

Financial Modeling for Investments

Stream: Financial Modeling, Risk Management and Managerial Accounting (contributed)
Contributed session
Chair: Roy Cerqueti

1 - Asset Pricing on Multiple Segmented Markets
Ahmed Badreldin, Bernhard Nietert

Despite continuous deregulatory efforts, investors are still confronted with unequal access to asset markets partly due to legal restrictions (unequal access to foreign and domestic stocks, short sale constraints) and partly due to investors' decisions (to invest only in "ethical" investments, or only in stocks where they have complete information), leading to market segmentation. The literature has a solid understanding of asset pricing on segmented markets with a single restriction, but does not know much about markets where more than one restriction exists (multiple segmented markets). For that reason, we analyze risk premia on multiple segmented markets. We find that risk premia of assets, from which some investors are excluded, equal risk premia on unsegmented markets and a term that reflects the demand deficit caused by excluded investors. This term becomes greater, the more investors are restricted from investing, and the more the risk premia between segmented and unsegmented markets diverge. However, these risk premia are not empirically applicable since they contain investors' unobservable risk preference parameters. Thus we re-express unobservable risk preference parameters with the help of observable (factor) portfolios. Finally, we apply simulations to analyze the statistical and economic significance of the identified differences in risk premia.

2 - Stochastic frontiers and efficiency for investments
John Lamb

The literature using data envelopment analysis (DEA) to estimate efficiency of investments such as hedge funds is well established. The literature applying stochastic frontier analysis (SFA) for the same purpose is very limited. This is surprising. SFA is better suited than DEA to stochastic data. And the most common form of the frontier in SFA matches what we might expect for investments. We investigate the problems in applying SFA to estimate the efficiency of investments and find several issues have been ignored. SFA assumes input and output variables are measured without error and that any deviation from the efficient frontier is composed of two components: an inefficiency, usually estimated with a truncated normal distribution and a random variation from the true frontier. Both components are assumed to be homoscedastic. It is straightforward to show that none of these assumptions are reasonable for investment funds and we show how to overcome them.

3 - Asset allocation with social impact investments
Massimo Biasin, Roy Cerqueti, Emanuela Giacomini, Luca Riccetti, Anna Grazia Quaranta, Nicoletta Marinelli

Besides their social impact, Social Impact Investments (SII) are an asset class that can be used for portfolio allocation. However, few studies investigated the risk-return performance of SII and their utility for portfolio allocation. Following La Torre, Chiappini and Mango (2017), we perform an investigation of how Social Impact Firms (SIF) contribute to portfolio risk and return performance. Using a unique dataset of 50 listed companies that meet the majority of the OECD requirements for SII, we build a social impact finance stock index (SIFSI) and compare the out-of-sample results for portfolios including or not the SIFSI among the feasible assets. The analysis is performed in terms of returns, Sharpe ratio, utility and forecast premium based on a Constant Relative Risk Aversion (CRRA) function for investors with different level of risk aversion. Following Riccetti (2013), the portfolios are built with different methodologies: naïve, Markowitz (1952) mean-variance optimization, GARCH-copula model. Overall, our macro asset allocation show the importance of a large portfolio slice committed to the SIF investments. Therefore, investors should closely monitor SIF firms in order to include their stocks in their portfolios.

4 - Learing by Going effect in product pricing
Sándor Danka

In our work we are dealing with a general dynamic model for maximizing profits in which demand depends on both price and quality. It is well known that price is a function of quality, but it is not a trivial question to define quality. The work attempts to explain quality, the factors that effect quality, and the way quality can be endogenously and exogenously altered. The answer to these questions are inevitable to implement quality into the model. As literature well describes the phenomenon of learning by doing, we will try to extend this manner of progression in the current economic state encompassed with ground breaking business models, disruptive innovations, closed loop value chains, and many other that modify many baseline consequences.

■ MC-28

Monday, 12:30-14:00 - G102

Finance and Banking 1

Stream: Decision Making Modeling and Risk Assessment in the Financial Sector
Invited session
Chair: Georges Tsafack

1 - Consumption-Based Downside Risk
Georges Tsafack

Investors care about the relationship between stock returns and the real economy. They also display an asymmetry behavior toward the ups and downs of their consumption. In a general equilibrium framework where the representative agent exhibits a disappointment aversion, we show how asset returns reflect both the downside risk premium and the upside discount. Empirical evidence show that downside consumption beta is a strong predictor of future stock returns. The risk premium based on downside consumption is however relatively low compared to premium when the market is used as a proxy.

2 - Stabilizing financial networks via mergers and acquisitions
Markku Kallio, Aien Khabazian

We analyze the benefits of mergers and acquisitions to stabilize a financial network. For identifying autonomous choices for banks to merge, we consider both the marriage model of stable matching and competitive bidding. Given mergers, for the evaluation of the financial network we extend the Eisenberg-Noe model taking into account bankruptcy and liquidation costs, and different seniorities of liabilities. Importantly, to avoid excessive deadweight losses we assume that corporate bonds of solvent banks can be used (in addition to cash) for clearing payments. For crisis resolution, the social planner (SP) may provide some bail-outs helping to cover the liabilities of the insolvent bank. We develop a bi-level model to identify the SP's best subsidizing policy. In this model, the SP's welfare loss function is minimized by simultaneous choice of subsidy levels, pairs of banks for mergers and the clearing equilibrium, taking into account that mergers need to be based autonomous choices of banks. For demonstration we use major European banks and a scenario which is linked to the adverse economic scenario used in 2016 EU-wide stress testing.The results show that the total subsidy for resolving a serious crisis may well be within the funds of SRF of the European banking union.

3 - Understanding spill-over effects in financial constraints for UK SMEs

Antonia Gieschen, Raffaella Calabrese, Jake Ansell, Belen Martin-Barragan

Small and Medium sized Enterprises (SMEs) represent a very diverse group of firms, though, there are often dependencies amongst them. This dependency arises from both the business networks to which they belong, as well as spatial spill-overs and business demographics such as their industrial sector. Many of these dependencies are opaque to those exploring SME behaviour. This paper examines the use of spatio-temporal clustering, using available information about SMEs to explore the dependencies which cast light on their behaviour. Our approach allows segmentation of the SMEs, identifying important variables in the development of spatial econometric regression models based on W matrices to represent spatial and business demographics. This can have the computational benefit of creating a sparse W matrix of dependency. Our prime focus in this research is the banking acceptance of SMEs for loans and overdrafts. Previously it has been established that there are spatial aspects relating to closeness to the banking system, with rural areas gaining relatively fewer acceptance than large urban centres. Another study discussed a connection between interdependencies among London SMEs including their spatial location and prediction of default. Our results demonstrate the importance of accounting for the spatial distribution of financial variables in the risk assessment of SMEs.

4 - Detecting Market Manipulation and Abusive Trading Using Anomaly Detection Techniques

Robert James, Artem Prokhorov, Henry Leung

This study presents a novel unsupervised procedure to identify instances of manipulative/abusive trading in financial markets, addressing the shortcomings associated with existing rule based expert systems. It is considered that manipulative trading strategies produce abnormal patterns in the time series of trading activity, making such manipulation detectable even in the absence of explicit assumptions regarding its form. Utilising the Dynamic Time Warping algorithm to measure the similarity between discrete sequences of individual market participant trading activity, the procedure flags instances of highly anomalous trading as potentially manipulative. The threshold defining the boundary between normal and manipulative behaviour is constructed using kernel density estimation applied to historically observed similarity scores associated with legitimate trading activity and leverages concepts from extreme value theory. Using real world, tick-by-tick transaction data provided by a global investment bank we highlight the utility of the procedure in identifying instances of insider trading and demonstrate its competitiveness with respect to several benchmark algorithms used in related literature.

■ MC-29

Monday, 12:30-14:00 - C118

Metaheuristics for Diverse Applications

Stream: Metaheuristics
Invited session
Chair: *Fred Glover*
Chair: *Gary Kochenberger*

1 - GRASP with solution blending for maximum weight independent set problem

Mauricio Resende, Yuanyuan Dong, Andrew Goldberg, Julien Michel, Nikos Parotsidis

We consider the problem of finding a maximum weight independent set on an undirected graph. We describe a path-relinking intensification phase to the GRASP of Feo, Resende and Smith (1994) for the maximum weight independent set problem. An extension of path-relinking, called solution blending, is introduced. We describe computational results on conflict graphs, a type of undirected graph arising in the post-optimization of line haul trip planning.

2 - A Tutorial on Formulating and Using QUBO Models

Fred Glover, Gary Kochenberger

The Quadratic Unconstrained Binary Optimization (QUBO) model has gained prominence in recent years with the discovery that it unifies a rich variety of combinatorial optimization problems. By its association with the Ising problem in physics, the QUBO model has emerged as an underpinning of the quantum computing area known as quantum annealing and has become a subject of study in neuromorphic computing. This tutorial discloses the basic features of the QUBO model that give it the power and flexibility to encompass the range of applications that have thrust it onto center stage of the optimization field. We show how many different types of constraining relationships arising in practice can be embodied within the "unconstrained" QUBO formulation in a very natural manner using penalty functions, yielding exact model representations in contrast to the approximate representations produced by customary uses of penalty functions. We also describe recent innovations for solving QUBO models that offer a fertile avenue for integrating classical and quantum computing and for applying these models in machine learning.

3 - The Flexible Job-Shop Scheduling Problem with complex precedence constraints

Grigoris Kasapidis, Dimitris Paraskevopoulos, Panagiotis Repoussis, Christos Tarantilis

The flexible job-shop scheduling problem (FJSSP) is a well-studied combinatorial optimization problem, which can be used to describe a wide variety of production scheduling problems. One of the main assumptions of the FJSSP is the linear nature of precedence relations between the operations of a job, which makes the formulation of the problem unable to map complex relations among operations that are often encountered in practice. In this paper, we introduce a new extension of the FJSSP that considers complex precedence relations among operations of a job, where an operation may have multiple predecessor and successor operations. A scatter search algorithm is proposed to solve the problem that uses specific data structures and mechanisms to assist the search process in an efficient manner. The proposed algorithm features a path relinking component that enables the recombination of multiple solutions towards a better sampling of the solution space. The performance of our scatter search (SS) algorithm was tested on well-known FJSSP instances. The proposed SS was able to produce 11 new best solutions on large-scale FJSSP instances of the literature, while being highly competitive overall. New and modified FJSSP instances with complex precedence constraints were generated using a new problem generator. The latter problems were also solved by a MIP and a CP solver of CPLEX and extensive computational results and comparisons are presented.

4 - A metaheuristic for scenario (and solution) generation

Beatriz Brito Oliveira, Maria Antónia Carravilla, José Fernando Oliveira

Uncertainty is a recent and critical challenge in OR. Scenarios are important tools to deal with uncertainty but the scenario generation process is often unrealistically simplified. We propose that metaheuristics, namely based on genetic algorithms, can generate relevant and complex scenarios. This is of particular interest in practical applications where there are many uncertain parameters, such as the integration of fleet management and pricing for car rental companies under demand and competitor pricing uncertainty. Considering this two-stage stochastic problem, we propose an innovative method based on a co-evolutionary metaheuristic, where solutions and scenarios are generated and evolve in parallel. The goal of the evolution of the solution population is to obtain values for the first-stage decisions that perform well when compared with the scenario population. The goal of the evolution of the scenario population is to diversify the impact of its elements on the profit of solutions. A current extension of this work is a scenario generator based on this idea of impact diversity. It is built on a BRKGA framework and can be easily adapted for different problems.

■ MC-30

Monday, 12:30-14:00 - C007

Data Science and Optimization

Stream: Data Science Meets Optimization
Invited session
Chair: Patrick De Causmaecker

1 - A Decision Support System for Job Dispatching in the Weaving Process - a Case Study in Taiwan
Wen-Chih Chen, Cheng-Hung Wu

This talk presents a real application in the textile industry in Taiwan, particularly focusing on a decision support system for job dispatching in the weaving process. The system intends to utilize the historical data collected from the manufacturing systems to provide decision aid. We identify the core practical challenges for job dispatching in the weaving process. We show how analytics and machine learning can help resolve the challenges. We also share our experiences on how to interact with and to promote business analytics to the industry practitioners.

2 - Acquiring Non-Linear Constraints
Mohit Kumar, Stefano Teso, Luc De Raedt

Most problems in Operations Research involve non-linear objectives and constraints over multi-dimensional decision variables, for instance personnel schedules or packing configurations. Modelling such problems is far from trivial. Usually domain experts are tasked with manually specifying the model, which can be both difficult and expensive. We propose an approach to partially automate the modelling step based on Artificial Intelligence and Machine Learning principles. We introduce a learning approach able to acquire non-linear satisfaction and optimization models from examples of feasible solutions, which are often available in many real-world OR tasks. In our approach, the main challenge is to efficiently explore the space of candidate models, which is extremely large. Indeed, enumerating all candidates is infeasible for all but the simplest OR tasks. To tackle this challenge, we design an efficient strategy that avoids exhaustive enumeration by exploiting a general-to-specific traversal of the space of modelling constraints. Further, the proposed method can acquire both hard and soft (weighted) constraints. Our empirical results on real-world problem instances (taken from Minizinc benchmark repository) showcase the promise of the approach.

3 - Perturbing Polynomially Solvable Problems
Patrick De Causmaecker, Chao Li, Pieter Smet

In the first part of this talk, we discuss polynomially solvable instances of nurse rostering problems in their most general form. The space of such instances can be described in a systematic way and may be considered a starting point for approximation. In the second part of the talk, we look for real world instances involving constraints that break polynomial time solvability. In particular, we look for instances that do not deviate too much and can be considered perturbations.

■ MC-31

Monday, 12:30-14:00 - G108

Stochastic modelling in healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Brian Denton

1 - Increasing utilization of available organs for transplantation
Burhaneddin Sandikci, Sait Tunc, Bekir Tanriover

We study incentive mechanisms to increase the utilization of available organs for transplantation to alleviate the burden of shortages, through a queueing-theoretic framework. We investigate socially efficient and equilibrium utilization of donor organs, and introduce an incentive mechanism that help increase the utilization while also improving overall social welfare. We also present detailed simulation results quantifying the magnitude of impact of this incentive mechanism for the U.S. kidney transplant system.

2 - Modeling uncertain task compliance in the dispatch of volunteers to out-of-hospital cardiac arrest patients
Vangelis Angelakis, Niki Matinrad, Tobias Andersson Granberg, Nicklas Ennab Vogel

Volunteers are an emergency response resource that has been facing a rising interest in the past few years. Many projects are utilizing semi-organized volunteers for daily emergencies and the number of these projects is increasing. Among them, the SMS life savers (https://www.smslivraddare.se/) started in 2010 as a research project in Stockholm, Sweden, and now is operational in both Stockholm and Gothenburg. SMS life savers are registered volunteers contributing in out-of-hospital cardiac arrest (OHCA) cases. Although the positions of these volunteers are known, it is not trivial to decide which and how many volunteers to dispatch, or who should go directly to the patient and who should collect an AED en route to the patient. Moreover, uncertainties associated with the response, e.g. the task compliance of volunteers, complicate the dispatch problem. Focusing on the latter, in this work, uncertainties associated with the volunteers' actions once assigned a task are explicitly modeled. This is done by taking into account the probabilities of mission abort, non-complying actions, and full compliance to instructions for each task assignment. We present a method to determine how the available volunteers should be dispatched in order to maximize OHCA patient's survivability. Results, based on historical data of the SMS life savers project, indicate a potential improvement in patient's survivability compared to the algorithm used in the SMS life savers project today.

3 - Supporting visits-based capacity planning in community care through novel computer simulation models
Christos Vasilakis, Manon De Prez, Richard Wood

With the ageing population in developed countries, the growing prevalence of chronic diseases and national trends to move away from treating patients in hospitals, community care is becoming increasingly important to relieve pressure from acute care settings. Unlike hospital beds though, capacity in community care is typically organised on a visits basis, with care professionals attending patients at their home or some other appropriate community facility. At the start of their engagement with community care, patients are often in need of more frequent visits by care professionals, with the need decreasing over the length of the engagement. While there are examples in the literature of modelling visits-based capacity, this particular aspect of community care makes the development of simulation models more intriguing. We present a time-driven simulation model we developed in the R programming language and software environment. The aim of our study was to help with estimating capacity for those community teams who deliver care to patients whose care needs decrease over time. We used the model to conduct a number of what-if and sensitivity analyses using the case of a stroke rehabilitation and care service. Simulation results uncovered the interesting dynamics at play and showed that, perhaps unsurprisingly, the different approaches of introducing the differential care need of patients in the model has an impact on capacity estimation.

■ MC-32

Monday, 12:30-14:00 - G109

Biological Data Analysis

Stream: OR in Life Sciences
Invited session
Chair: *Pawel Wojciechowski*

1 - Detection of Hidden Patterns in Time Series Data via Multiple-time FOD Method
Ekin Can Erkuş, Vilda Purutcuoglu

The periodicity in time series data can be detected by several frequency domains' methods, especially, by the Fourier transform (FT). FT is a non-parametric method to convert the time domain data into the frequency domain and it is used in many engineering and data science applications. Recently this method which has been used to detect outliers in time series observations where the data may also include some systematic patterns is called "outlier detection via Fourier transform" (FOD). From our previous analyses via real and simulated time-course datasets, it has been shown that FOD is a promising technique to find periodic and non-periodic outliers in the data, particularly, when the sample size increases and the data are far from normal distribution. On the other hand, it has been observed that the multiple application of FOD is successful in order to detect the hidden patterns in real electrocardiogram (ECG) datasets since the pattern of FOD signals indicates differences between control and various types of heart diseases. Therefore, we consider that they can be applied for the pre-diagnosis of certain heart illnesses. In this study, we aim to extend the multiple time FOD by evaluating its performance comprehensively under distinct Monte Carlo scenarios such as different sample sizes, distributions and percentage of outliers. We consider that these analyses can be helpful to detect outliers and hidden patterns in distinct time-series data including ECG datasets.

2 - Integrated Data Analysis of Gene Expression and Structural Variation Data of A. Thaliana
Aleksandra Swiercz, Giovanni Felici, Agnieszka Zmienko

Copy number variation (CNV) strongly affects the expression of the genes in the cells. It has been observed in the literature that CNV influences gene expression and can lead to several diseases. In this study we analyzed publicly available data sets of the plant Arabidopsis thaliana, composed of 1060 samples of DNA sequencing data, which were transformed into copy number of each gene (CNV) and 728 samples of transcriptomic data set, which is the gene expression.

Genes were first clustered according to the values of the expression and the number of copies each gene appears in the genome. Automatic clustering method was not accepted by the biological experts because the standard method measuring the distance of the CNV vectors did not take into account the difference of the duplication and deletion signals. Later, we classified genes with the threshold levels of copy numbers giving only 9 groups differing in the number of deletions or duplications of those genes in different plants. In the 9 groups we analyzed the correlation of CNV and gene expression with the significance of the p-value. We searched for the dependencies of the deletion of the gene and its lower expression in the tissue.

The conclusions are to be confirmed by the biological experiments.

3 - Population Scale Analysis of Copy Number Variations in Arabidopsis Thaliana
Pawel Wojciechowski, Agnieszka Zmienko, Malgorzata Marszalek-Zenczak

Copy number variation (CNV) plays a crucial role in modelling intra-species genetic variation. We created a dataset of CNVs detected by broad analysis of short read data stored in 1001 Genomes Project. The selected 1064 highest quality DNA libraries were subjected to our integrated CNV discovery analysis, which relied mainly on a combination of three main types of read signatures used in CNV identification: read depth, discordant read-pair mappings and split-reads utilizing their main pros at an appropriate step of analysis. Finally, AthCNV dataset - the set of 19 thousands of CNVs were identified at the population level. The first step of accuracy investigation was a comparison of AthCNV with analysis of CNV based on Oxford Nanopore long read sequencing for a selected accession. The next step was genotyping the genomic regions that undergo CNVs for each individual by GenomeSTRiP. A selected samples were experimental validated by preparing a multiplex ligation-based probe amplification (MLPA) data for a set of genes and compared to GenomeStrip results.

■ MC-33

Monday, 12:30-14:00 - Q005

Economic modelling and game theory I

Stream: Dynamics and Games
Invited session
Chair: *José Manuel Gallardo Morilla*

1 - Market coverage with quality dependent unit production costs
Margarida Catalão-Lopes, Cesaltina Pires, Sílvia Jorge, Pedro Garcês

This paper identifies the equilibrium quality choices in a vertically differentiated market with price competition, when the unit production costs are increasing with quality. Besides the partial coverage and full coverage equilibrium, we consider cases where the Nash equilibrium involves full market coverage but with a corner solution in the price game. We identify when each of the market coverage configurations holds. This article completes and corrects previous results on vertically differentiated models.

2 - Vessel sharing agreements: a robust approach
Federico Quartieri

The last decades have witnessed a trend towards concentration in the container shipping industry. In most cases such a trend derives from the formation or the enlargements of vessel sharing agreements. These consortia provide for the joint use of their members' production means while retaining the individual legal identities thereof. From a modelling perspective the mentioned industries can then be viewed as oligopolistic games where the freight rate (i.e., prices) for the service provided by a member is affected by the all carriers of the industry while its (fixed and variable) costs are affected only by the members of the consortium to which it belongs. A comparative statics analysis about the competitive effects of the formation and enlargement of vessel sharing agreements has been conducted in Quartieri [2017, Economics of transportation]. The present contribution provides a more robust approach to such a comparative statics analysis by considerably generalizing the assumptions on the class of price functions to that examined in von Mouche and Quartieri [2018, Optimization], showing that the special type of generalized concavity introduced in the last-mentioned paper well-suits to comparative statics problems.

3 - Stackelberg competition of newsvendors selling substitutable products
Ganesh Balasubramanian, Sachin Jayaswal

We study a stylized model inspired by the inventory decisions faced by two competing e-retailers for their substitutable products with limited shelf lives and uncertain demands. Before the start of the selling season, both the e-retailers need to decide the stocking quantity of their products. However, one of them (henceforth called the follower) always takes its stocking decision only after observing online the stocking decision made by the other (henceforth called the leader). Due to the limited shelf lives of their products, the two e-retailers face the risk of leftover inventory, on which they incur a loss. At the same time, due to substitutability of the two products, each e-retailer faces the risk of losing a portion of her customers to the other, in case she runs out of stock during the selling period. In the Stackelberg game described above, which involves the risk of leftover inventory due to demand uncertainty, it is not obvious if the leader should use her first mover advantage by stocking a monopoly (newsvendor's) quantity. Will the leader ever use her first mover advantage to order less than the follower, especially when the overstocking cost is high? We prove that under identical cost structures and independent and identically distributed demands, the leader should never stock less than the follower. Under unidentical cost structures, we present conditions under which the leader's optimal ordering quantity is less than that of the follower.

4 - A characterization of the Shapley value for cooperative games with fuzzy characteristic function
José Manuel Gallardo Morilla, Andrés Jiménez-Losada

The characteristic function of a cooperative game determines the payment that each coalition can obtain when the players in the coalition cooperate. But there are cooperative situations in which the players have only imprecise expectations about the profit that can be achieved by each coalition. In order to model these situations, in 2001 Mareš and Vlach introduced cooperative games with fuzzy characteristic function, in which the payment of each coalition is a fuzzy quantity. A value for these games assigns to each player in a game a fuzzy quantity that indicates the vaguely expected payoff for the player. Mareš introduced a Shapley value for games with fuzzy characteristic function, but, so far, no characterization of it has been given. We present a characterization of this value.

■ MC-34

Monday, 12:30-14:00 - Q006

Session in Honour of Bernard Roy

Stream: Multiple Criteria Decision Making and Optimization (contributed)
Invited session
Chair: Alexis Tsoukias

1 - Session in Honour of Bernard Roy
Alexis Tsoukias

Bernard Roy, former EURO President, EURO Gold Medal, EDSM award of EURO, is among the most important personalities of OR in Europe the last 50 years with contributions spanning from graph theory and scheduling to Multiple Criteria Decision Analysis and Decision Aiding Practice. The session is dedicated to his multiple achievements and the legacy of his contributions.

2 - Bernard Roy and the EWG-MCDA (A talk in honor to Bernard Roy)
José Rui Figueira, Roman Slowinski, Salvatore Greco

This is a talk in honor to Bernard Roy. Contents: 1. The Very Beginning. 2. An important member" of the Group. 3. Main Purposes of the EWG-MCDA. 4. Organizational Aspects. 5. Cerisy-La-Salle. 6. Research. 7. Impacts on the Field. 8. His Last Meeting. 9. Friendship (Social Programs). 10. Some Remembrances (souvenirs)

3 - Talk in honour of Bernard Roy
Dominique de Werra

Short talk in honour of Bernard Roy.

4 - Talk in honour of Bernard Roy
Vincent Mousseau

Short communication in honour of Bernard Roy contributions to MCDA

5 - The last interview of Bernard Roy
Marta Bottero

Short presentation of the last scientific interview of Bernard Roy.

6 - Talk in honour of Bernard Roy
Daniel Vanderpooten

Short talk in honour of Bernard Roy contributions.

■ MC-35

Monday, 12:30-14:00 - Q009

Game Theoretical Models and Applications I

Stream: Game Theory, Solutions and Structures
Invited session
Chair: Izabella Stach

1 - Preference Rankings and Proportional Representation: Mismatches in Germany, 2005-2017
Frank Steffen, Matthew Braham, Mostapha Diss

As with all proportional list systems, the German system is afflicted by a fundamental inconsistency known as the More-Preferred-Less-Seats-Paradox. Although this has been known to be a theoretical possibility for a long time, it has never been demonstrated empirically for Germany. We follow a method previously applied to studies of elections in Denmark (1973-2005) and The Netherlands (1982-1994) that reconstructs these preference rankings from opinion polling data. We use flash polls that contain 'thermometer data' on party preferences conducted the week before polling day for the Federal Elections in 2005, 2009, 2013, and 2017. The main finding is that each of the elections has been afflicted by the paradox. Qualitatively, it is arguable that the occurrence of the paradox in 2005 and 2009 is relatively benign. But in 2013 and 2017 the paradox took on a different dimension. Firstly, in 2013 the liberal Freie Demokratische Partei (FDP) actually dropped out of parliament although being preferred over the leftwing party DIE LINKE, which was the so-called Condorcet-loser (or least-preferred party). DIE LINKE was the third largest faction in the Parliament and the official opposition. Then in 2017, the populist rightwing party, Alternative für Deutschland (AFD), received the third largest seat share although, as with DIE LINKE in the previous election, it was the Condorcet-loser and it too has become the official opposition.

2 - A method to calculate the (p,q)-bisemivalues
Margarita Domènech, José Miguel Giménez, María Albina Puente

We introduce a subfamily of bisemivalues called (p,q)-bisemivalues and as a particular case of it, we find the binomial bisemivalues, that extend the concept of binomial values to bicooperative games. The (p,q)-bisemivalues can be used in the study of bicooperative games because they offer a deal of flexibility greater than the values defined up to now, and hence many more possibilities to introduce additional information when evaluating a game. They provide tools to study not only games in abstracto(i.e. from a merely structural viewpoint) but also the influence of players' personality on the issue. In the (p,q)-bisemivalue case two parameters are used to cope with different attitudes the players may hold when playing a given game, even if they are not individuals but countries, enterprises, parties, tradeunions, or collectivities of any other kind. For all player, we will attach to parameter p the meaning of generical tendency to support a player in his decision and to parameter q generical tendency to go against him. We think that these bisemivalues are suited for the study of bicooperative games where players show two different tendencies to form coalitions. Players' tendencies can encompass a variety of situations that cannot be analyzed, without modifying the game, by means of another values, which are concerned only with the structure of the game. We also give a computational procedure in terms of the multilinear extension of the game to calculate them.

3 - Extending power índices to (3,2)-games
Montserrat Pons, Josep Freixas

Different power indices defined in simple games can be obtained under a similar probabilistic approach by: 1) establishing a bargaining model, 2) deciding which kind of winning coalitions are assumed to be formed. The power indices which can be defined under this approach include, among others, the well-known Banzhaf, Johnston or Deegan-Packel índices. When extending these power indices to (3,2)-games a third important aspect must also be considered: the notion of criticality which should be used.

4 - Measuring Power in Corporate Networks
Izabella Stach, Jacek Mercik, Cesarino Bertini

This work discusses some game-theoretical methods that measure indirect control in complex corporate shareholding networks. These methods used power indices in order to estimate the direct and indirect control of firms in shareholding structures. Some of these methods only estimate the control power of investors (firms without shareholdings), and only a few measure the control power of all firms involved in shareholding networks (which means investors and stock companies). Neither takes measuring the importance of mutual connections (edges in networks) into consideration. Thus, we focus particularly on an extension of these methods in our research in order to measure not only the control-power of firms involved in complex shareholding structures (represented by nodes in networks) but also the importance (power) of linkages between the firms as elements of a whole corporate shareholding network. More precisely, we apply our approaches to a theoretical example of a corporate network. Moreover, we continued the considerations started in Mercik and Stach (2018) about the reasonable properties for indirect control measurement.

■ MC-36
Monday, 12:30-14:00 - Q010

Inventory Routing II

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Luca Bertazzi*
Chair: *Demetrio Laganà*
Chair: *Birger Raa*

1 - Consistent stochastic inventory routing with time windows
Emilio Jose Alarcon Ortega, Karl Doerner

In this paper, we present an Inventory Routing Problem that aims to minimize the total cost of developing efficient replenishment and delivery plans considering several characteristics. We introduce the Consistent Stochastic Inventory Routing Problem with Time Windows (CSIRPTW). In this problem, customer face stochastic demands horizon given by a probability distribution over a set of periods, defining a finite planning. Moreover demands present continuous consumption rates within the periods that, in the later, create the possibility of incurring in stock out situations within the periods. Customers also demand consistency in delivery times in order to anticipate the deliveries and present different time windows related to opening times. After formulating the CSIRPTW we propose three different solution approaches in order to obtain efficient solutions. The first method consist on a matheuristic solution approach that integrates an ALNS with a Sample Average Estimator. The second solution approach is an adaptation of the Branch-and-Regret heuristic for stochastic and dynamic vehicle routing problems. The third method is a multiple scenario approach that evaluates different demand realizations and creates efficient routes to minimize average costs. In the last step, we present computational comparisons between the proposed methods and managerial insights using an adapted benchmark set of instances.

2 - A heuristic approach for the Multi-attribute Inventory Routing Problem
Annarita De Maio, Demetrio Laganà, Leandro Coelho

In this work, a mathematical formulation and a heuristic algorithm for the Multi-Attribute Inventory Routing Problem (MAIRP) are proposed. The problem is defined on a logistic network in which a vendor has to deliver different classes of products from a set of depots to a set of customers with a heterogeneous fleet of vehicles, while limiting the time duration of routes. The objective of the problem is to jointly minimize depots and customers inventory costs and the transportation cost, while satisfying customers' demands and avoiding stock-out. The MAIRP is a NP-hard problem more complex than the classical Inventory Routing Problem. Nevertheless, it captures several of features that can be found in real applications of the vendor-managed inventory setting. We introduce a hybrid algorithm to solve it, in which several Mixed Integer Programming models based on route variables are solved to explore the neighborhoods of a Variable Neighborhood Search scheme applied to the MAIRP. Neighborhoods' exploration is embedded into a branch-and-cut algorithm working on a small portion of the whole search space. The algorithm alternates the two phases related to the local search and the branch-and-cut by considering a series of rules.The impact is to accelerate the resolution process with respect to other approaches used for the MIP standalone. We design several neighborhoods that are based on the features of the problem, and we present computational results on several benchmark instances.

3 - A matheuristic for the inventory routing problem with divisible pickup and delivery
Simen Vadseth, Henrik Andersson, Magnus Stålhane, Einar Aastveit

This paper considers an inventory routing problem with divisible pickup and delivery (IRP-DPD). A customer may have both delivery and pickup demand in this problem type and is allowed to have separate servings for pickup and delivery. The last part is contrary to what is common and is what constitutes a so-called divisible option. A single depot with a fleet of homogeneous vehicles is considered. The vehicles are restricted by capacity and a maximal duration for a route. An arc-flow formulation of the problem, formulated as a mixed integer linear program, is proposed as an exact solution approach.The exact approach with an extended branch and cut algorithm solves smaller instances to optimality and finds feasible solutions for some larger instances.

To solve larger instances, a matheuristic with a two-phase construction approach followed by an improvement search is proposed. To construct a solution the matheuristic decomposes the problem into an inventory problem and a routing problem. The constructed solution is further improved with a set of operators. The matheuristic embeds the construction and the improvement operators into an iterative scheme. When the iterative loop is terminated, a final improvement search is suggested. The matheuristic gives solutions with lower dual gaps than the exact method for all larger instances. It also finds good solutions faster and produces feasible solutions for instances where the exact method does not.

4 - Evaluating formulations and branch-and-cut algorithms for the cyclic IRP
Birger Raa, Leandro Coelho

We consider the cyclic inventory routing problem (IRP), where multiple retailers with constant demand rates and limited storage capacities are replenished from a single depot over a given multi-day planning horizon, while minimizing the total cost rate. This total cost rate consists of the fixed cost of the required vehicles, the vehicle routing costs and the retailers' inventory holding costs. The same multi-period solution will be cyclically repeated, hence the retailers' ending inventory levels must match their initial inventory levels.

For solving small-size instances of this cyclic IRP, we propose two mathematical formulations and evaluate various implementations of branch-and-cut (B&C) algorithms to solve these formulations.

With regards to the formulation, the complication is in the fact that a vehicle can make multiple trips per day, within a limited amount of time. One formulation has routing variables defined per trip, requiring extra variables to assign trips to vehicles. The alternative formulation has routing variables defined per vehicle, requiring extra variables to track which retailer is in which trip.

Concerning the B&C algorithms, the major challenges are coming up with valid inequalities to tighten the formulations and identifying which constraints to add in the root and which as lazy constraints. Based on solving a set of benchmark instances, insights are provided on the formulations as well as the performance of various B&C implementations.

■ MC-37

Monday, 12:30-14:00 - Q011

Dynamic and Stochastic Scheduling

Stream: Scheduling with Resource Constraints
Invited session
Chair: *Wim Vancroonenburg*
Chair: *Sanja Petrovic*

1 - A matheuristic approach for conveyor operation optimization
Farzaneh Karami, Wim Vancroonenburg, Greet Vanden Berghe

Large distribution centers generally employ conveyor networks to transship commodities from specific loading to unloading locations. Each section of a given network has a limited capacity and takes a certain amount of time to transport commodities. To optimize conveyor operations we aim to solve the problem of transferring a given amount of flow between the set of loading and unloading locations within a minimum makespan. Makespan is defined as the point in time when the last unit of flow reaches its unloading location. In this study, we introduce and compare dynamic flow-based and path-based problems: the multi-commodity quickest flow problem (MCQFP) and the multi-commodity quickest path problem (MCQPP). The MCQFP concerns the transshipment of flow from multiple loading locations to multiple unloading locations on a fixed path during a given time horizon such that the last unit of flow arrives at its unloading location as early as possible. On the other hand, the MCQPP targets the same objective but with respect to an unknown number of paths. A heuristic is also proposed to solve the MCQPP. Experiments are conducted on benchmark instances and high-quality computational results are presented and discussed.

2 - Online Coordination Scheduling for Distributed Satellite System with limited Communication
Guoliang Li

This paper focuses on online management of Distributed Satellite System under dynamic environment. In reality, the inter-satellite communication is limited by practical reasons. The objective is to maximize the total profit of whole system subject to communication time window constraints and observation time window constraints. Firstly, Contract Net Protocol (CNP)-based mechanism is presented to solve this problem. Then, we propose two novel online coordination mechanisms based on Synchronous and Asynchronous communication respectively. The two proposed online coordination mechanisms are compared with CNP-based mechanism. Computational experiments indicate that when the communication resources are scarce, Synchronous Communication-based mechanism is the best choice for the balance between the profit and the communication cost. When the communication resources are relatively sufficient, Asynchronous Communication-based mechanism is preferred for the good performance on profit and percentage of scheduled urgent tasks.

3 - Online Scheduling of Jobs with Agreeable Deadlines
Kamal Al-Bawani

Job scheduling is a central problem in the area of combinatorial optimization and arises in many real-life applications- whenever simultaneous tasks (jobs) are to be assigned to limited resources (machines). In real-time systems, each job has a deadline before which it must be completed. As resources are limited, not all jobs can be finished in due time, and thus the goal of scheduling algorithms is to maximize the number of jobs that are finished before their deadlines. In most scenarios, jobs have different weights (priorities) and thus we aim to maximize the total weight of completed jobs.

Often in reality, jobs are not known before their arrival, i.e., the processing time, weight and deadline of a job are revealed only when the job arrives. Problems of this kind are called "online". In this work, we address the problem of online scheduling on one machine. It is known that without any restriction on deadlines and processing times, no online algorithm achieves a throughput that is within a finite factor of the optimal throughput, even if all jobs have weight 1 [Baruah94]. Therefore, we consider the special case of agreeable deadlines, i.e., for any two jobs i and j, if i arrives before j, then i expires before j. We first show that even in this case, no online algorithm can be within a finite factor of the optimal throughput. We then consider a further restriction where all jobs have the same processing time and show an online algorithm that is optimal in this case.

4 - Energy-aware scheduling aspects in parallel high-performance stencil computations
Milosz Ciżnicki, Krzysztof Kurowski, Jan Weglarz

The performance of most powerful high performance computing (HPC) systems has already achieved the pre-exascale level in the form of multi-node supercomputers. Stencil computations are common in numerical parallel code and they are used in a wide range of scientific applications. Taking into account both relevant characteristics and requirements of stencil computations we have proposed the theoretical scheduling model and proved that it is possible to achieve the substantial savings in the execution time and energy costs of stencil computations. However, our approaches for finding optimal configurations of stencils on different processor chips, as well as heuristics to schedule stencils in real time dealt with heterogeneous computing node only. In practice, the data locality and the overall performance of stencil computations are determined not only by dividing the problem size properly, and then scheduling data and execution tasks on heterogeneous processors, but also on detailed mapping of the communication dependencies of the blocks to the communication topology in large number of computing nodes. The aim of the follow up studies was to propose some extensions of scheduling model and to generalize the proposed heuristics taking into account new characteristics extracted from real multi-node HPC network topologies. We also demonstrate how the generic scheduling model can be adopted to better predict the runtime and the energy usage of stencil computations.

■ MC-38

Monday, 12:30-14:00 - Q012

MCDA and Environmental Management 1

Stream: Multiple Criteria Decision Aid
Invited session
Chair: *Antonio Boggia*
Chair: *Lucia Rocchi*
Chair: *Filippo Fiume Fagioli*
Chair: *Luisa Paolotti*

1 - A multi-criteria analysis for evaluating environmental performance of poultry farms in Umbria Region, according to European Legislation
Luisa Paolotti, Matteo Piersantelli, Lucia Rocchi, Filippo Fiume Fagioli, Antonio Boggia

Since the 1960s, the International policies for sustainable development and a growing awareness of society regarding environmental issues have led also the livestock production sector to adopt more sustainable practices. On 24 September 1996, the Integrated Pollution and Prevention Directive - IPPC was introduced in Europe, which provides obligation to release an environmental authorization for the activities identified by the same legislation. The IPPC is a procedure to evaluate the environmental compatibility of the production activities that could determine significant environmental problems, such as polluting emissions in atmosphere, water and soil, or in relation to the waste management and natural resources consumption. The most important innovations introduced by this authorization are a significant simplification of the authorization process, and the Best Available Techniques - BAT. In this framework, the objective of this work is to assess a group of poultry farms subjected to IPPC, taking as case study a number of farms located in the Umbrian region. The main purpose is to identify the most efficient alternative in the environmental field and the necessary improvements, in order to evaluate the level of sustainability of the farms, also in relation to the prescriptions of BAT. The ranking of sustainability has been obtained by means of Electre II evaluation method (Roy, 1991 and 1996; Roy and Bertier, 1971), which is part of non-monetary valuation methods.

2 - A multicriteria tool based on FADN Italian dataset to assess the socio-economic and environmental sustainability of agricultural systems under different scenarios

Guido Maria Bazzani, Giuliano Vitali, Concetta Cardillo, Maurizio Canavari

The paper illustrates a tool designed to assess the socio-economic and environmental sustainability of agricultural systems based on the Italian FADN dataset. The tool relies upon a set of mathematical programming models designed to cope with the available data in a multi-criteria fashion. Models incorporate the views of different stakeholders, including producers, consumers, and policymakers, and entail the identification of alternatives land uses and management options that determine specific economic, environmental, and social impacts. Indicators related to production cost, market prices, gross income as well as the use of fertilisers, labour and machinery allow identifying the impacts. We present a case study considering the Emilia-Romagna Region, which is located in the Po valley, North Italy, and represents one of the main agricultural production areas in the country. The study, based on data collected in the period 2012/2016, analyses alternative arable land use at the aggregate level, under different scenarios. Results show that this approach can support the identification of feasible cropping schemes and management options that are perceived as sustainable by the different stakeholders on the basis of the given indicators. This approach can also support the construction of a common vision since it allows exploring and comparing proper policy intervention alternatives.

3 - Environmental valuation and MCDA: where we are going

Lucia Rocchi, Luisa Paolotti, Antonio Boggia

Multicriteria decision analysis (MCDA) has been recognized as a crucial tool in environmental decision making. Decision making in environmental sciences has to balance a broad range of consideration, incorporating scientific data and, at the same time, including stakeholder interests. Flexibility in analysis design and access to a range of sophistication in analytic tools are part of the appeal of MCDA for environmental decision making. The aim of the work is to analyze trend in applications of MCDA in the environmental sciences. The work reviews frequency and diversity of MCDA use within the environmental discipline, applying text mining. Text mining is a method capable to face a large number of text items. Thus, it is an efficient way to analyze a large body of literature and detect patterns and trends. Survey literature text mining involves data collection, cleaning and preprocessing analysis, results evaluation. The analysis was grounded on an initial search for the term 'environ' in SCOPUS database, reviewing articles, conference papers and book chapters published between 2009 and 2018. Then, for cleaning the corpus, we refined the analysis using MCDA keywords and environmental phrases. Cleaning and preprocessing analysis produced a corpus of 2566 documents. The result of the work is the analysis of the quantitative data obtained through the text mining process and the frequency of use of MCDA methods and applications within the environmental decision making.

■ MC-39

Monday, 12:30-14:00 - Q014

Project management: planning, scheduling, and success factors

Stream: Project Management and Scheduling
Invited session
Chair: *Massimiliano Caramia*
Chair: *Patrick Gerhards*

1 - Scheduling Multi-Release R&D projects

Ran Etgar, Yuval Cohen

While projects are described as one-time effort to achieve a specific goal, many typical R&D projects are often ongoing efforts planned for multiple releases and without a specific single end. This phenomenon is not new but never has it been so widespread and prevalent. There are many examples such as iPhones, MS-Office, communication equipment and SW versions that are released to the market at spaced time intervals. Version release planning is a complex problem, as appropriate understanding of planning objectives and technical constraints are required for a good release plan. The problem faced by both practitioners and researchers is the allocation of features to releases subject to limited resources. Typically, each feature is composed of several activities, and since the activities are often shared by several features, this problem becomes extremely complex. Since, Current project scheduling techniques fail to provide helpful plans, there is a need to develop novel methods for these projects. This research aims to develop scheduling tools for multiple-releases ongoing projects. The suggested scheduling algorithm incorporates methods taken from the field of clustering and data analysis, that culminates in several techniques that provide near-optimal solutions. The developed methods were tested on a database (based on PSPLIB) and proved superior to human best practice and other methods.

2 - 2-types Fuzzy Sets in Models of the Duration of a Project Affected by Risk

Barbara Gladysz

Using PERT, one assumes that the time required to carry out the individual tasks in a project can be approximated using a beta distribution. It is assumed that the parameters of these distributions (the minimum, maximum and most likely times) are estimated by experts in accordance with the properties of the beta distribution. However, this is not always the case. This article shows how one may analyse the time required to carry out a task. This article presents a method for timetabling a project affected by risk. The times required to carry out tasks are modelled using 2-types fuzzy sets. The parameters of fuzzy times of tasks are given by experts: one corresponding to the duration of a task in stable conditions, with no risks materializing, and the other corresponding to the duration of a task in the case when risks do occur. Finally, a case study will be presented and analysed.

3 - Measuring Project Success in accordance with project selection

Isaak Vryzidis, Athanasios Spyridakos

Project success consists from two components: a) Project Management Success and b) Product success. The first component refers to the efficiency of the project team to deliver the project within scope, budget, time and quality constraints, while the second component focuses on the effectiveness of the project itself - customer satisfaction, stakeholders' satisfaction and achievements regards to the business goals. The main challenges of measuring project success are: 1) the project impacts which could be obtained either short-term after project completion or usually long-term after it and 2) the difficulty to synthesize the different qualitative and quantitative parameters of different point of views in one success verdict. The proposed approach for the project success measurement is based on Multi-Criteria Analysis, which is utilized in order to estimate an additive value system according to selection criteria. A combination of the disaggregation - aggregation multicriteria decision aid UTA methods and the Multi-Objective Linear Programming Techniques are used in the project selection phase. In the second phase, a multi-criteria effectiveness map is suggested for the qualitatively pairwise composition of different perspectives. The effectiveness map utilizes a developed set of indices capturing the deviations from the initial strategic planning and a set of indifference thresholds aiding the decision maker with the final conclusions.

4 - The decentralized multi-mode resource investment problem: a multi-agent based project scheduling problem
Patrick Gerhards, Andreas Fink

In this talk, we propose an extension of the multi-mode resource investment problem (MRIP). The MRIP is a project scheduling problem with a fixed deadline and renewable and non-renewable resources. The amount of available resources is variable and each extra unit of resource is associated with resource costs. In addition, each activity of the project can be processed in one of several modes that determine the resource usage as well as the activity duration. The goal is to find a schedule and a mode assignment that minimises the resource costs while respecting precedence relations, resource consumptions, and the deadline. In the decentralized version (DMRIP) of this problem, we assume that more than one party conducts a project. We call the subjects involved with the project agents. Each agent is responsible for some of the activities of the project. The agents have to reach an agreement on how global resources are shared (i.e. the costs of these resources as well as the usage of the resources in each period of the project horizon) and when the activities start and end. The aim is to find negotiation protocols that do not rely on providing sensitive information by the agents. Each agent aims to minimise her or his resource costs. We present a distributed schedule generation scheme and apply it in several negation protocols for this complex scheduling problem.

■ MC-40

Monday, 12:30-14:00 - Q015

Maritime Transportation I

Stream: Maritime Transportation
Invited session
Chair: Grzegorz Siekaniec

1 - A metaheuristic approach for a Berth Allocation Problem
Fernanda Peteam, Kelly Cristina Poldi, Marcia Ruggiero

Increasing trade in products between different continents has made it increasingly important to optimize the process of shipping goods. Thus, the optimization of the allocation process of the ships in the ports has been studied a lot through the Berth Allocation Problem (BAP). Such problem consists in assigning the ships to berths, aimming to minimize the cost of attendance of the ships, usually determined by the service time of the ships that consists of the sum of the time they spend waiting for berthing and the time of handling cargo. In this research we deal with the dynamic and discrete BAP case, where the ships may arrive during the planning horizon and the port is considered to be formed by a finite set of berths. In this research we apply the BRKGA metaheuristic to the BAP modeled as a Vehicle Routing Problem and then the results are compared with the literature.

2 - The Economic Operational Speed of a Time-Chartered Ship - A Cash Flow Approach
Fangsheng Ge, Patrick Beullens, Dominic Hudson

It is well recognized that ship speed is an important variable affecting fuel consumption and emissions, and that in ocean shipping average ship speeds, ceteris paribus, decrease with bunker price but increase with freight rates. Empirical data suggests that identical ships in the bulk cargo and tanker industry, travelling identical routes under identical economic conditions, still travel within a wide distribution of speeds. The reasons for this cannot be well understood from current speed optimization literature. The models developed in this article lead to increased understanding of how optimal speed decisions are dependent on the charter contract, which sets out conditions that determine the relevant future to the decision maker. A wide range of different ship speeds would then be observed as a consequence of deliberate choice, i.e. profit-maximizing behaviour.

3 - An integrated vessel schedule and aggregated cargo route recovery model.
Grzegorz Siekaniec, David Franz Koza, David Pisinger, Emil Sokoler

Despite a precisely established plan, disruptions are a reality in liner shipping. They are caused by unforeseen factors such as weather, port congestion, low terminal productivity, crane breakdowns etc. Disruptions vary in magnitude. Smaller disruptions, such as the temporary stop of a crane operations due to fog, often impacts only a single vessel. In contrast, the closure of a hub terminal as Algeciras for two days due to rough weather in Gibraltar Straits has severe ripple effects that spread across the entire network. Recovery actions for such major events require rescheduling of multiple vessels, as well as cargo re-routing. Maersk, in cooperation with the Technical University of Denmark, is working on a decision support tool aimed at recovering operations after disruptions of different sizes in near real time. The tool uses an integrated approach that jointly optimizes vessel schedules and cargo routes. The objective is to minimize (a) operational cost, mainly vessel related such as fuel and port stays, and (b) impact on cargo delivery dates. The outcome is "cargo-friendly" revised vessel schedules that recovers operations within a fixed time horizon. The practical considerations and mathematical formulation of the model(s) will be presented together with preliminary computational results.

4 - Liner-Network Shipping Design with Autonomous vessels
Mohamed Kais Msakni, Kjetil Fagerholt, Elizabeth Lindstad, Frank Meisel

Maritime transportation is witnessing an interesting opportunity by introducing autonomous vessels. With no crew on-board, autonomous vessels can be built with no deck house and no crew facilities. An immediate impact is reduced operational costs and more shipped cargoes. However, despite the real benefits to the existing shipping mode, international regulations per today limit the introduction of fully autonomous vessels in international waters. Norway, as one of the largest shipping nation, is highly motivated by introducing autonomous vessels, and authorities are positive for using autonomous vessels. In this regard, we propose to study a liner-network shipping design problem to transport goods from the European continent to Norway, and vice versa. This problem aims to find the best network design by determining the optimal fleet of vessels (number and size), and the route of each vessel. According to the current regulations, we assume that the network is based on mother and daughter vessels. Conventional mother vessels sail on a main route that links the European continent to the main Norwegian ports, while autonomous daughter vessels have smaller capacities and are intended to transport cargoes from main ports to the ports located at the Norwegian coastline. In this study, an optimization model is developed to find cost-effective network routes and is applied to a case study to show the economic benefits of introducing autonomous vessels.

■ MC-41

Monday, 12:30-14:00 - Q013

Robust Public Transport Optimization

Stream: Public Transportation I
Invited session
Chair: *Konstantinos Gkiotsalitis*
Chair: *Francesco Alesiani*

1 - Robust optimization of stop-skipping strategies for bus operations

Konstantinos Gkiotsalitis

Planning which stops should be skipped (also known as stop-skipping or expressing) is a typical strategy in bus operations and helps to improve the balance between demand and supply. The planning of stop-skipping strategies is typically based on the expected travel times of bus trips. Notwithstanding, this has a positive effect in practice only if the traffic conditions during the daily operations do not deviate significantly from the expected ones. For this reason, this work proposes a non-deterministic approach which considers the uncertainty of trip travel times. We model the stop-skipping optimization problem as a robust optimization one where we seek the stop-skipping strategy that performs the best in a worst-case scenario. After that, we show how historical travel time observations can be integrated into a Genetic Algorithm (GA) that tries to compute a robust stop-skipping strategy for all daily trips of a bus line. The proposed mathematical program of robust stop-skipping at the tactical planning stage is solved using the minimax principle, whereas the GA implementation ensures that improved solutions can be obtained even for high-dimensional problems by avoiding the exhaustive exploration of the solution space. The proposed approach is validated with the use of 5-month data from a circular bus line in Singapore demonstrating an improved performance of more than 10% in worst-case scenarios which encourages further investigation of the robust stop-skipping problem.

2 - How to increase modal shift of freight transport towards public transport network

Francesco Alesiani, Gulcin Ermis

Despite the societal interest to shift freight transport from the road towards public transport infrastructure and despite the potential gain in terms of costs, the low reliability of the freight public transport has led to extensive use of roadways. We address the concern of the distribution and collection network by proposing a model which integrates the Train Unit Scheduling Problem (TUSP) and Vehicle Routing Problem (VRP), in a way that (1) preserves anonymity (2) is robust to public network delays and (3) maximizes the satisfaction of customer requests. The VRP model incorporates the delay distribution of the public network. This model is used to define the TUSP solution that best meets the distribution and collection capability, without the need to disclose the end customer locations. The solution of the first problem is based on the Robust VRP (R-VRP) that considers the assigned capacity and consequent demand per time slot at the dispatching point in the distribution network (respectively the destination node in the collection network). The TUSP assigns the train units, which represent the R-VRP demand. Since the VRP is limited in the vehicles' working times, the ability to serve customers depends on the arrival time distribution. This research is partially funded by EU' Horizon 2020 RIA GA 769141 (COG-LO), while EU is not responsible for the content.

3 - A Robust Rolling Stock Rescheduling Model

Joris Wagenaar

Effective disruption management in passenger railways is currently an active research area in Operations Research. This has lead to many papers on algorithmic tools for rescheduling the timetable, rolling stock and crew schedule. In this paper the focus is on rescheduling the rolling stock. All existing models assume the duration of a disruption given at the time of rescheduling. However, in practice the duration of a disruption is uncertain, so in case new information about the duration of the disruption is available, the rolling stock must be rescheduled again. No information about a possible change in the disruption duration was taken into account when rescheduling the rolling stock the first time, thus it is only optimized with respect to a single possible duration. In case the disruption lasts longer, decisions taken in the past might turn out to be (very) costly.

In this paper a model is proposed that is able to reschedule the rolling stock in a robust way with respect to the duration of disruption. Even more, we are able to give a full robust or semi-robust solution. In case of a full robust solution all important trips are robust against different disruption durations and in case of a semi-robust solution at least a given percentage of the trips must be robust against different disruption durations. Next to that, we will demonstrate that robustness comes at a price and we will show what this price is for different practical settings.

4 - Robust Periodic Timetabling

Julius Pätzold, Anita Schöbel

Optimizing timetables for public transportation has been an extensively studied topic, not only because of its intrinsic hardness, but also due to its social relevance. One important problem in this context is the Periodic Event Scheduling Problem (PESP). Most PESP research investigates optimizing the passengers' travel time solely for some default scenario, usually a scenario where no train is delayed. In practice, however, there exist train delays that need to be dealt with. In order to find timetables that can cope well with these delays, our approach is to consider not only a single default scenario, but rather a whole set of likely scenarios. To carry out this idea and furthermore integrate the public transport problems of timetabling and delay management we extend PESP by incorporating robust optimization. In this work we present a solution approach for the robust PESP. In our work, we apply the concept of strict robustness and present an algorithm that, given a set of delay scenarios, finds a timetable yielding best travel times in its worst case scenario. Such a problem structure can be solved by an iterative scheme similar to cutting plane methods. This approach can be sped up by solving the occurring MILPs only approximately, i.e., to a specified gap. We implemented the solution algorithm in LinTim and show that for small to medium instances optimal robust timetables can be found. The retrieved timetables show good worst-case behaviour even in aperiodic settings.

■ MC-42

Monday, 12:30-14:00 - Q113

Safety in transportation

Stream: Transportation
Invited session
Chair: *Carlo Liberto*

1 - Surrogate measures of safety in roundabouts: a comparative study based on extreme value theory

Riccardo Rossi, Massimiliano Gastaldi, Federico Orsini

Roundabout safety analysis traditionally involves the use of crash data, which are affected by many problems: they suffer from under-reporting and misclassification, are often only available in an aggregated manner, they must be collected for long periods of time and/or at many intersections, to accumulate sufficient data for analysis. In addition, the crash data approach is reactive, meaning that a significant number of collisions must occur before action can be taken. Extreme value theory (EVT) can be used in road safety research for safety analysis without the need of crash data. This work presents a comparative study to evaluate the use of various surrogate measures of safety for EVT applications in roundabout safety analysis. Two well-known surrogate measures of safety were tested: Time-To-Collision (TTC) and Post-Encroachment-Time (PET). Data were collected during a driving simulator experiment, in which testers were asked to perform multiple entering maneuvers in a roundabout. EVT distributions were fitted with both Block-Maxima (BM) and Peak-Over-Threshold (POT) approaches. The predicted numbers of collisions of the models were compared with the actual number of collisions observed during the experiment. Results from this case study indicate that PET is to be preferred in roundabout EVT applications, because it produces better results, in terms of both model fitting and collision prediction, although TTC may still be considered a viable alternative.

2 - A methodology for evaluating the speed mitigating effect of an overhead sign illuminated crosswalk
Sergio Maria Patella, Francesco Asdrubali, Francesco Bella, Stefano Carrese, Claudia Guattari, Marco Petrelli, Simone Sportiello

This research presents the definition of a new methodology for evaluating how illuminated crosswalks influence drivers' behavior when approaching the zebra under nighttime visibility conditions. The proposed method is based on three different measurements. These are performed in two zebra-crosswalk sections, similar in terms of roadway geometry, except that one includes an overhead sign, projecting light downward to improve the visibility of pedestrians, while the other is an unsignalized crosswalk. The measurements are: 1) road markings illuminance for the illuminated crosswalk, 2) retroreflectivity coefficient for the unsignalized (non-illuminated) crosswalk, 3) vehicles speed profile for both sections. The visibility of non-illuminated pavement markings at night depends on their retroreflectivity, and the reflection under vehicle headlamp illumination is measured with a retroreflectometer. A lux meter is used to measure the vertical illuminance on the vehicle. The meter is held against the vehicle 1.5m above pavement, facing in the direction toward the crosswalk. For both sections vehicle speed measurement is performed with laser-based speed and distance measurement instrument. The speed is measured on randomly selected vehicles which approach the zebra in free flow conditions. By comparing the results of the two sections, this work demonstrates that the presence of an overhead sign in a crosswalk section has a speed mitigating effect, even in the absence of pedestrians.

3 - Agent-based simulation to modelling pedestrian behaviours
Carlo Liberto, Stefano Carrese, Marialisa Nigro, Cristiano Zarelli

Pedestrian safety is a primary requirement in the configuration of urban areas and it is particularly relevant for public gathering spaces, such as railway and underground stations, stadiums or shopping malls. Besides, the quality and the comfort level of the available walking environments play a key role in the challenge of sustainable mobility. For these reasons, over the last twenty years, there has been a growing interest in developing methodologies for modelling and analysing the walking transport mode. The overall aim of our work is to contribute in investigating the collective phenomena and emerging properties that can be crucial in the realistic characterization of pedestrian dynamics. We propose an agent-based model that is able to simulate the interactions between individuals and the environment. Individuals are represented by computational entities (agents) able to reach spatial goals avoiding collisions with other agents and obstacles. Each agent is characterized by several parameters, like the desired speed, the field of view, etc. Inspired by "Social Force Models", we encode the rules of the pedestrian's behaviour into an equation of motion. Eventually, we use this model to simulate pedestrian flows in a variety of conditions. Our first findings show a good agreement of the simulations with empirical data and results in the literature, suggesting that this work can actually contribute in increasing the efficiency and safety of pedestrian flows dynamics.

■ MC-43

Monday, 12:30-14:00 - Q114

Hub Location I

Stream: Location Analysis and Optimization
Invited session
Chair: Francisco Saldanha-da-Gama

1 - A multiple-allocation profit maximizing p-hub location problem considering hub congestion, time-sensitive demands and 1-stop paths
Armin Lüer-Villagra, Elena Fernández, Vladimir Marianov

Hub location models are used to design communication and transportation networks in different industries. Fundamental hub location models have been extended to consider profit maximization, hub congestion, price-sensitive demands and multiple stops in every origin-destination (OD) path, etc.

We formulate and solve a problem where a profit-maximizing company wants to design a p-hub and spoke network. The transportation demands react to total travel time, which is the arc travel time plus hub processing time; hubs are congested by inbound flows; and every OD path includes at most one hub. This challenging model is solved using an ad-hoc solution method that integrates Lagrangian relaxation and column generation.

Ongoing research includes extensive computational experiments to show properties and stability of our novel approach. Future lines of work are the extension of our model to include capacity selection at the hubs, and two or more hubs in OD paths and more sophisticated cost structures.

2 - Solving Multi-Objective Hub Location Problems with Robustness
Enrique Dominguez, Miguel A. Dominguez, Francisco Chicano, Gabriel Luque

Hub location problems (HLP) are considered in many logistic, telecommunications, and computer problems, where the design of these networks are optimized based on some objective(s) related to the cost or service. In those cases, direct routing between any origin and destination is not viable due to economic or technological constraints.

From the seminal work of O'Kelly, a huge number of works have been published in the literature. Early contributions were focused on analogue facility location problems, considering some assumptions to simplify the network design. Recent works have studied more complex models by incorporating additional real-life features and relaxing some assumptions, although the input parameters are still assumed to be known in most of the HLPs considered in the literature. This assumption is unrealistic in practice, since there is a high uncertainty on relevant parameters of real problems, such as costs, demands, or even distances. Consequently, a decision maker usually prefer several solutions with a low uncertainty in their objectives functions instead of the optimum solution of an assumed deterministic objective function.

In this work we use a three-objective Integer Linear Programming model of the p-hub location problem where the average transportation cost, its variance, and the processing time in the hubs are minimized. ILP solvers can only solve small instances and we propose in this work the use of a recent hybrid algorithm named CMSA.

3 - Risk-averse hub location problem
Kamyar Kargar

In this study, we introduce risk-aversion concept in the hub location problem where the objective function is defined by a coherent risk measure. We present risk-neutral and risk-averse two-stage stochastic formulations for uncapacitated multiple allocation p-hub median problem and discuss the impact of risk-aversion on the structure of the network. We also propose an algorithm based on scenario decomposition for solving the problem. To evaluate the performance of the proposed solution algorithm, a set of computational experiments is conducted and the results show that the proposed approach is very effective in finding high quality solutions in significantly shorter computation time than that of CPLEX.

4 - Heuristic solutions for a class of stochastic uncapacitated p-hub median problems
Francisco Saldanha-da-Gama, Angel Corberan, Rafael Marti, Juanjo Peiró

We propose a heuristic procedure for a stochastic version of the uncapacitated r-allocation p-hub median problem with nonstop services. In particular, we assume that the number of hubs to which a terminal can be allocated is bounded by r. Additionally, we consider the possibility of shipping traffic directly between terminals (nonstop services). Uncertainty is associated with the traffic to be shipped between nodes and with the transportation costs. If we assume that such uncertainty can be captured by a finite set of scenarios, each of which with a probability known in advance, it is possible to develop a compact formulation for the deterministic equivalent problem. However, even for small instances of the problem, the model becomes too large to be tackled by a general solver. This fact motivates the development of a heuristic procedure, whose starting point is the determination of a feasible solution to every (deterministic) single-scenario problem. These solutions are then embedded into a process based on the path relinking methodology: gradually an initial solution to the overall problem is transformed by the incorporation of attributes from some guiding solutions. In our case, the guiding solutions are those found for the single-scenario problems. We report and discuss the results of the numerical experiments performed using instances randomly generated for the new problem from the well-known CAB and AP data sets.

■ MC-44
Monday, 12:30-14:00 - Q115

Non-Standard Decision-Making Methods

Stream: Non-Standard Optimization and Decision-Making Methods
Invited session
Chair: *Jaroslav Ramik*
Chair: *David Bartl*

1 - Conditions of Order Preservation in Pairwise Comparisons Matrix With Fuzzy Elements
Jaroslav Ramik

In this paper we deal with Condition of Order Preservation (COP) of pairwise comparisons (PC) matrix with fuzzy elements. Fuzzy elements are appropriate whenever the decision maker (DM) is uncertain about the value of his/her evaluation of the relative importance of elements in question, or, when aggregating crisp pairwise comparisons of a group of decision makers in the group DM problem. We formulate the problem in a general setting investigating pairwise comparisons matrices with elements from abelian linearly ordered group (alo-group). Such an approach enables extensions of traditional multiplicative, additive or fuzzy approaches. We review the approaches known from the literature, then we propose our new order preservation concept based on alpha-cuts. We define the concept of consistency of PC matrix with fuzzy elements (FPC matrices). We derive the necessary and sufficient conditions for strict consistency as well as weak and strong POP conditions and relationships. Finally, we deal with some consequences to the problem of ranking the alternatives. Illustrating examples are presented and discussed.

2 - A Discrete Variant of Farkas' Lemma and Related Results
David Bartl

In the setting of a module over a linearly ordered ring (such as the ring of the integer numbers), we report a discrete variant of Farkas' Lemma. The result is reported in full generality, without any additional assumptions about the ring. We then mention related results, namely Tucker's Key Theorem, Motzkin's Theorem and Tucker's Theorem of the alternative, which follow from the new result. Finally, we hint at possible applications in optimal business decision making. First, we consider an enterprise facing several future scenarios (events) with the likelihood (probability) and the worst impact score of each event being given. We propose that the probabilities and scores attain values in a special linearly ordered ring with zero divisors. Assuming that the impact of an event can be mitigated if the enterprise makes an investment into preventive measures and given a limited budget, a linear optimization model follows. Second, we briefly note that it also makes sense to use the special linearly ordered ring with zero divisors in the FMEA (Failure Mode and Effects Analysis) method.

3 - Fuzzy Decision Analyzer
Radomir Perzina, Jaroslav Ramik

There exists wide range of software products to support decision making. Main disadvantage of those software products is that they are commercial and relatively expensive and thus it prevents them to be used by small companies, students or researchers. This paper introduces a new online tool FDA - Fuzzy Decision Analyzer which is completely free and was developed to support users in multicriteria decision making situations with uncertain data. It can be also used by students to help them understand basic principles of multicriteria decision making, because it doesn't behave as a black box but displays results of all intermediate calculations. The proposed software package is demonstrated on an illustrating example of a real life decision problem.

4 - Power Evaluation in Group Decisions under Uncertainty - Evidence from the Czech Parliament 2010-2017
Elena Mielcová

The main aim of the paper is to show a possible application of the I-fuzzy set approach to the real world situation. Namely, contribution discusses a construction of Shapley and Banzhaf values for cooperative games with I-fuzzy coalitions and their application on real data - in this case the voting data from the Chamber of Deputies of the Czech Parliament 2010-2017. This approach incorporated two possible sources of uncertainty, namely defection of legislators in their presence and their party loyalty. Result indicate that the discrepancy in correlations between power indexes of political groups and their success can be partially solved by incorporating uncertainty issues into power index calculations. However, the results also led to the idea, that there are more factors that have to be incorporated into concept of power indexes for better expression of predictions of future power distribution among political groups.

■ MC-45
Monday, 12:30-14:00 - Q117

Transportation and uncertainty

Stream: Transportation and Logistics
Invited session
Chair: *Manuel Fuentes*

1 - Characterizations for DTA modelling under user equilibrium conditions and convergence of solutions for stochastic DTA cases
Ricardo de la Paz Guala, Cristian Cortes, Pablo A. Rey

In the study of the phenomena that affect traffic, such as the interaction of different instances that intervene in a transport network, or the behavior of users and the characteristics of the infrastructure, the analysis of traffic assignmemt is a fundamental tool. In recent years, due to contributions in new methodologies and advances in technologies, the problem of dynamic traffic assignment of the demand (DTA), which seeks to understand in a more realistic way the interactions between the transport network and the behavior of users when considering the time dependancy of their choice of route and/or departure time under certain conditions, such as user equilibrium (UE), becomes determinant, when it comes to analyzing this study area. Particularly, in order to understand that the choices of drivers who join an urban transport network vary from one another, it is necessary to consider stochasticity when generating DTA models (SDTA). In this paper, explicit characterizations of the fundamental functions that define the DTA, under EU conditions, for some transport network structures are given and, as a conclusion of computational testing followed by analytical analysis, it is presented that, under certain circumstances, the SDTA, under EU conditions and considering a discrete choice of route based on a logit model, converges and, after a bounded instant in time, is equal to the solution of the DTA case. Some examples are studied to ilustrate this results.

2 - The ways for optimizing drivers behavior based on the demand estimation and order probability prediction
Aleksandra Panyukova, Tatiana Makarovskikh

Our report covers development of methods that could be used as one of subsystems of a platform that provides information and transaction services for business-to-client communication. For example, these methods may be used for alerting managed objects (performers, using taxi drivers) to influence their management decisions in order to increase business efficiency and reduce operational costs. We estimate the demand for transportation needs using available statistics on taxi orders and develop a method for determining the coordinates of the place with the highest order probability, depending on the time of day and the current location of the driver. The result is formatted for further transfer to the driver by bot message.

3 - Dynamic service network design for rail freight considering uncertain travel times
Tobias Pollehn, Daniel Haalboom

In single wagon load transport, shipments are routed through a hub-and-spoke network with several consecutive freight trains. Due to stochastic delays of trains, the planned railcar interchanges at the hubs are at risk of disruption. Late train arrivals lead to disrupted trip plans of commodities if the delay exceeds the slack of the train connection. However, increasing the slack can lead to less efficient use of hub capacity and increased transport times. Integrating stochastic travel time data in the service network design can therefore help to balance network efficiency and trip plan robustness. We propose a new formulation of a dynamic service network design model taking into account the probabilities of disruptions of railcar interchanges. The consideration of costs reflecting these probabilities will lead to more robust trip plans. By comparing our computational results with solutions based on deterministic travel times, we demonstrate the gains of integrating travel time uncertainty into service network design formulations.

4 - A microscopic approach for energy consumption and passenger compensation policy in disruption management
Manuel Fuentes, Luis Cadarso, Ricardo Garcia-Rodenas

In a railway network, incidents may cause traffic to deviate from the planned operations making impossible to operate the schedule as it was planned. In such a situation the operator needs to adjust the schedule in order to get back to the original schedules.

A train operator may have the policy of economically compensating (e.g., refunding ticket fare) passengers when they incur in delays. Compensation levels usually depend in the amount of delay. Therefore, it is important to have a smart way of deciding whether to speed up trains in order to absorb delays, i.e., increasing energy consumption, or to compensate passengers.

In this paper a mathematical model which decides on the speed profile while considering passenger use is presented. The model decides on the optimal sequence of operating regimes and the switching points between them for a range of different circumstances and train types all while considering delays and passenger compensation policies applied by the train operator. The objective of this paper is to minimize both energy consumed and incurred compensation to passengers. Constraints on traction and braking forces, on train velocity, on forces caused by vertical and horizontal track profile, and on passenger compensation policy are considered.

Computational tests on realistic problem instances of the Spanish rail operator RENFE are reported. The proposed approach is able to find solutions with a very good balance between various managerial goals.

■ MC-46
Monday, 12:30-14:00 - L243

Optimization Problems Intertwined with Equilibria

Stream: Variational analysis, games and intertwined optimization problems
Invited session
Chair: *Giancarlo Bigi*

1 - Proximal regularization in bilevel optimization
Francesco Caruso, Maria Carmela Ceparano, Jacqueline Morgan

Recently a proximal regularization method has been used in a game theoretical framework in order to select a subgame perfect Nash equilibrium in one-leader one-follower games (Stackelberg games) when the optimal response of the follower to any choice of the leader is not always unique. It embeds the idea that players must face costs when they deviate from their current actions and it is motivated according to an anchoring effect that reflects the players' difficulties in changing actions (Caruso, Ceparano, Morgan: "Subgame perfect Nash equilibrium: a learning approach via costs to move", Dynamic Games and Applications 2018). In this presentation we move from the game theoretical setting mentioned before towards a bilevel optimization perspective, in particular simple bilevel optimization. We investigate approximation methods involving the proximal regularization: convergence results, examples and connections with bilevel optimization solution concepts are provided.

2 - An Augmented Lagrangian Method for Quasi-Equilibrium Problems
Luis Felipe Bueno, Gabriel Haeser, Felipe Lara, Frank Rojas

In this paper, we propose an Augmented Lagrangian algorithm for solving a general class of possible non-convex problems called quasi-equilibrium problems (QEPs). We define an Augmented Lagrangian bifunction associated with QEPs, introduce a secondary QEP as a measure of infeasibility and we discuss several special classes of QEPs within our theoretical framework. For obtaining global convergence under a new weak constraint qualification, we extend the notion of an Approximate Karush-Kuhn-Tucker (AKKT) point for QEPs (AKKT-QEP), showing that in general it is not necessarily satisfied at a solution, differently from its counterpart in optimization. We study some particular cases where AKKT-QEP does hold at a solution, while discussing the solvability of the subproblems of the algorithm.

3 - Viscosity solutions in bilevel optimization and games
Jacqueline Morgan, M. Beatrice Lignola

In bilevel optimization and games a pessimistic approach leads to introduce concepts of viscosity solutions which satisfactorily obviate the lack of solutions and which are defined through regularization families, called inner regularizations, of the solutions map to the lower level. In line with Lignola and Morgan (JOTA, 2017 and 2018), sufficient conditions for the existence of such viscosity solutions are given under possibly discontinuous data .

4 - Solving Quadratic Multi-Leader-Follower Games by Smoothing the Follower's Best Response
Steffensen Sonja

The multi-leader-follower game is a particular subset of classical game theory. These models serve as an analytical tool to study the strategic behavior of individuals in a noncooperative manner. In particular, the individuals (players) are divided into two groups, namely the leaders and the followers, according to their position in the game. Mathematically, this leads optimization problems with optimization problems as constraints.

We derive Nash-s-stationary equilibria for a class of quadratic multi-leader-follower games using nonsmooth best response function. To overcome the challenge of nonsmoothness, we pursue a smoothing approach resulting in a reformulation as smooth Nash equilbrium problem. We prove existence and uniqueness for all smoothing parameter. For a decreasing sequence of this smoothing parameters accumulation points of Nash equilibria exists and we show that they fullfill the conditions of s-stationarity. Finally, we propose an update on the leader variables for efficient computation and numerically compare nonsmooth Newton and subgradient methods.

■ MC-47

Monday, 12:30-14:00 - L247

Individual differences in OR-supported processes

Stream: Behavioural OR
Invited session
Chair: Aysegul Engin

1 - Activating the adequate thinking mode when making decisions - an analysis of visualisation techniques

Michael Leyer, Aysegul Engin, Jürgen Strohhecker

According to dual-processing theories, as, for instance, cognitive-experiential self-theory, individuals tend to rely more on either their slow, analytic or their fast, intuitive system when faced with a decision. While the debate, which one of the thinking modes is generally superior, seems unresolved, theory suggests that both ways can be successful if they match the characteristics and requirements of the decision making task. Poor performance is seen as a consequence of a mismatch: E.g., if a decision maker uses the analytical approach in a situation requiring intuitive (fast) thinking instead, there is limited benefit, but very likely much time lost. Attempts to improve this matching are often resource-intensive (e.g. training). Based on cognitive fit theory, a promising idea is to help individuals applying the appropriate thinking mode by providing a structural visualization the decision problem. We present first results from a 2x2 experiment in which we provide participants with graphical visualisation and table representation in two types of tasks that are chosen based upon whether analytic or intuitive processing would be most appropriate to successfully complete them. We control for certain characteristics such as information perception, information processing and cognitive load. The results are contributing to our understanding how decision making can be improved by activating the adequate thinking mode using visualisation.

2 - Irrational Maximisers: Are behavioural maximisers more prone to biased judgements than their satisficing counterparts?

Shashwat Pande, K.Nadia Papamichail, Peter Kawalek

In this paper, we investigate the central question of whether in certain circumstances, behavioural maximisers are in fact poorer decision makers compared to their satisficing counterparts. We draw on behavioural decision theory and the dual system paradigm to suggest that maximisers' denial of their bounded-rationality leads them to arbitrarily expand choice even when normatively preferable alternatives are available. We test our hypothesis in a series of experiments and our findings provide support for this claim. Specifically, we show that, a) maximisers demonstrate a lower preference for analytical information processing, b) in absolute terms, maximisers are more likely to adhere to a number of behavioural biases than their satisficing counterparts, c) their adherence to these biases is due to a reliance on easily comparable criteria, variety seeking and representativeness as non-compensatory information handling heuristics, and d) their adherence to biased responses persist even in situations where a biased alternative is dominated by an objectively superior choice or a normative choice is inaccessible. We discuss our findings with respect to their implications for a boundedly-rational view of unaided decision processes and suggest that the very behavioural strategies that maximisers adopt in their quest for the "best" alternative, predispose them to errors in judgement in a number of cases.

3 - Individual differences in model comprehension and use: A study of cognitive styles and cognitive mapping

Ilkka Leppanen, L. Alberto Franco

Do cognitive styles, value orientations, and conflict in values determine how decision makers comprehend and use cognitive maps? We set out to study this question with an experiment where subjects were tested on cognitive map comprehension and asked to make linking choices between different statements. A total of 185 subjects participated in an online experiment that consisted of two parts. In Part 1 the task was to recognise linking errors in a cognitive map that was constructed at a pre-study workshop. In Part 2 the task was to make linking choices in a map that was like the map in Part 1. We correlated behaviour in Part 1 to scores in Need for Cognition (NFCog) and Faith in Intuition (FI) trait scales, and the behaviour in Part 2 additionally to scores in the Allport values scale and self-reported conflictedness statements. We found that NFCog correlated positively with linking accuracy in Part 1, i.e. high NFCog subjects made less linking errors than low NFCog subjects, whereas FI did not correlate with linking behaviour. We also found that NFCog, FI and conflict were able to predict choices in some value domains and that FI had an inverse relationship to self-reported conflictedness. Our study draws a picture of how individual traits and capabilities affect cognitive map comprehension and use and demonstrates the importance of accounting for individual differences in model-supported managerial decision making.

4 - Variability in decision behaviour: An agent capital perspective

Chidinma Crystal Ulumma Chukwuemeka, K.Nadia Papamichail, Yu-Wang Chen, Richard Allmendinger

This work draws from the behavioural decision making and sociological disciplines to study ways in which individuals' career decision strategies are determined by the amount of capital they own. A key facet of behavioural decision theory is describing mechanisms through which beliefs/values influence decision making. Sociological theory of practice on the other hand, estimates predictors of the interactions between decision maker's and fields in their environment. A synergy of perspectives would indicate that changes in decision behaviour could be measured by evaluating the changes seen in individuals' navigation across and within fields. Hence adopting Bourdieu's practice framework, we assert that the portfolio comprising social, human,economic and cultural forms of capital owned and developed by an individual over time would explain their access, interaction and mobility within and across fields. The framework has been empirically tested using data from LinkedIn. We observed and analysed the recurrent career decision of 850 individuals, who have worked at least 5 jobs over their career span. The results indicate that a change in decision behaviour can significantly be explained by an agent's capital portfolio. These results are notable because they provide a framework for understanding the dominant strategy individuals would adopt when faced with critical decision problems as well as likely changes overtime. Finally, practical implications are discussed.

■ MC-48

Monday, 12:30-14:00 - L248

Biomathematical and Health modeling I

Stream: Applications of Dynamical Models
Invited session
Chair: *Bruno M.P. M. Oliveira*
Chair: *José Martins*
Chair: *Alberto Pinto*

1 - Applications of Weighted Markov Chain and Autoregressive Integrated Moving Average in the Prediction of Under-5 Mortality Rates in Nigeria
Phillips Edomwonyi Obasohan

In developing countries, correctly predicting the trend of the childhood mortality rate can provide a clear understanding to make health policy for mortality reduction. This paper aims to apply two methods (Weighted Markov Chain Model and Autoregressive Integrated Moving Average) to predict annual child mortality rate so as to establish which of these models better predict childhood mortality rate. The study will be conducted on the Childhood Mortality Annual Closing Rate (CMACR) data for Nigeria from 1964-2013. CMACR is a random sequence changing over time (annually), so we can analyze the mortality closing rate and predict the change range of CMACR in the next state. Weighted Markov Chain (WMC), a method based on Markov theory is mainly studying the state and its transition procedures to describe a changing random time series. On the other hand, Autoregressive Integrated Moving Average (ARIMA) is a generalization of an Autoregressive Moving Average (ARMA) Model. These models are fitted to time series data for better understanding of the data pattern and predictions of future values based on previous observed values. ARIMA model are specially build to serve as basis of standard structures in time series data, and as a result provides a simple yet powerful method for making significant time series predictions. Therefore we hypothesised that WMC Model predicts more accurately the childhood mortality rates in Nigeria than ARIMA

2 - Efficiency of subsidy versus targeting for vaccines
Alec Morton, Razzaque Sarker

Vaccination has a crucial role in the protection of populations from infectious disease. However, many new vaccines are expensive and to provide vaccines to the entire population may not be affordable, especially in poorer countries. Hence, in such settings there is a need for vaccination programmes to use public funds as efficiently as possible as part of a mixed financing strategy. In this paper we discuss the choice between subsidy and targeting of vaccination. We frame the problem as one of achieving a coverage goal at minimum public cost. We present an intuitive model for comparing the costs of targeting and vaccination and explore its structural properties, shedding light on when subsidy might be preferred to targeting and vice versa. In summary our analysis suggests that, as a rule of thumb, high prices favour subsidy and low prices favour targeting; and high goal levels favour targeting and low goal levels favour subsidy. We illustrate our model using demand data for cholera vaccination in Bangladesh.

3 - Inference of evolutionary dynamics of tumors as a scheduling problem
Pavel Skums, Vyacheslav Tsyvina, Alex Zelikovsky

Intra-tumor genetic diversity is one of the major factors influencing cancer progression and treatment outcome. However, evolutionary dynamics of cancer cell populations remains poorly understood. Quantification of selection during the tumor evolution is a key step to understanding mechanisms driving cancer. We present an algorithmic framework for inference of fitness landscapes of cancer clone populations from genomic data. It is based on a maximal likelihood approach, whose objective is to estimate a vector of clone fitnesses which better fits the observed tumor phylogeny, genomic composition of the cancer cell population and the specified evolutionary model. We show how to transform the original maximum likelihood problem into a discrete optimization problem, which could be considered as a variant of scheduling problem with precedent constraints and with non-linear cumulative cost function. In this problem, mutations play roles of jobs, history of mutation accumulation corresponds to a scheduling of jobs on a single processor, phylogenetic tree of the cancer cell population represent job precedence constraints, and the cost of processing a job at a given iteration is equal to the probability of observing the corresponding mutation at a given time. Finally, we propose an algorithm to solve this problem which uses branch-and-bound approach to find optimal solutions for its well-structured subproblems, and then combine subproblem solutions using dynamic programming.

4 - Dynamics of CD4+ T cells: fit to time series obtained after LCMV infection
Bruno M.P. M. Oliveira, Filipe Martins, Atefeh Afsar, Alberto Pinto

We fit a dynamical model of immune response by CD4+ T cells to unevenly spaced time series of data from mice infected with lymphocytic choriomeningitis virus (LCMV). We used an ODE model that considers both CD4+ T cells, regulatory T cells (Tregs) and interleukine-2 (IL-2) density. This model is able to fit both the immune activation phase following infection and the subsequent relaxation phase for the gp61 and NP309 LCMV epitopes.

■ MC-49

Monday, 12:30-14:00 - L249

Software for mixed-integer nonlinear optimization

Stream: Software for Optimization
Invited session
Chair: *Jaromil Najman*

1 - Recent developments of the supporting hyperplane optimization toolkit (SHOT) solver
Jan Kronqvist, Andreas Lundell

SHOT was originally developed for convex mixed integer nonlinear programming (MINLP) problems, and benchmarks have shown that SHOT is among the most efficient solvers for such problems [1]. It combines primal and dual algorithms for obtaining bounds on the optimal solution [2]. The dual algorithm is based on the ESH algorithm and generates outer approximations for obtaining iteratively improving lower bounds. The primal algorithm includes techniques for obtaining feasible solutions to the problem, giving upper bounds on the optimum. In its original form, the ESH algorithm is not well suited for nonconvex problems. The supporting hyperplanes may cut off parts of the feasible set, and result in an empty search space. Techniques to improve SHOT's nonconvex capabilities, including feasibility restoration, primal cuts, and reformulations, are presented. In its current form, SHOT only guarantees global optimality for certain types of nonconvex problems, and for general nonconvex problems it works as a heuristic. The new features have significantly improved the solver's ability to deal with nonconvexities, and the goal is to extend its global capabilities. [1] Kronqvist, J., Bernal, D. E., Lundell, A., & Grossmann, I. E. (2018). A review and comparison of solvers for convex MINLP. Optimization and Engineering. [2] Lundell, A., Kronqvist, J., & Westerlund, T. (2018). The Supporting Hyperplane Optimization Toolkit. Preprint, optimization-online.org/DB_HTML/2018/06/6680.html

2 - SDP based BQP relaxation strenghtening
Robert Luce

We consider the solution of binary quadratic programming (BQP) problems in the standard branch-and-bound framework. Unlike for the more general mixed-integer quadratic programming problem, the idempotency of binary variables allows for regularization of the objective function without altering the set of optimal solutions.

Such regularization can serve two purposes. First, it can be applied to ensure the convexity of the continuous relaxation, and secondly one can take advantage of this freedom to strengthen the root relaxation of (convex) BQP problems. In both cases choosing the "best" (in a particular sense) regularization results in an auxiliary semi-definite programming problem.

We discuss different computational techniques for the exact and approximate solution of this SDP, along with some simplistic heuristics. An overall assessment of this approach, based on the implementation in Gurobi v8.1 on a large set of BQP's will be given.

3 - EAGO.jl, Easy Advanced Global Optimization in Julia

Matthew Stuber

The Julia programming language was developed for both extreme speed and ease-of-use motivated by high-performance computing and engineering/scientific modeling and simulation applications. Thus, Julia offers enumerable capabilities and enormous flexibility for a broad range of mathematical programming activities including algorithm development, testing, and deployment to advanced modeling, design, and analysis.

In this work, we present the EAGO.jl package which is the community's first deterministic global optimization software platform for general nonconvex nonlinear programs in Julia. The EAGO platform was developed specifically with advanced problem formulations (e.g., semi-infinite programs (SIPs), dynamic programs, embedded simulation, etc.) in mind, offering: a flexible and user-customizable (via API) spatial branch-and-bound framework; a state-of-the-art McCormick relaxation library including standard, generalized, multivariate, and differentiable relaxations; an interval arithmetic library; interfaces for Julia's JuMP and MathProgBase optimization modeling languages; an SIP solver; routines for implicit functions; interfaces for linear and (local) nonlinear solvers; automatic differentiation routines; advanced constraint propagation and domain reduction routines; and advanced routines for expression graph decomposition and analysis. We will discuss EAGO's core features and demonstrate its applicability and performance.

4 - MAiNGO - McCormick-based Algorithm for mixed-integer Nonlinear Global Optimization

Jaromil Najman, Alexander Mitsos

MAiNGO is a deterministic global optimization software for the solution of mixed-integer nonlinear programs (MINLPs). It is applicable to MINLP consisting of factorable Lipschitz continuous functions. We have shown it to have computational advantages for classes of problems that admit reduced-space formulations, such as commonly found design problems. The main distinction of MAiNGO compared to other global solvers, is the operation in the original optimization variable space through the application of McCormick relaxations. This is done through the open-source library MC++ (Chachuat et al. IFAC-PapersOnline 48 (2015), 981). Additional features are custom relaxations for various functions (including functions relevant to process systems engineering), and significant flexibility in model formulation. In addition to the spatial branch-and-bound and some well-known bound tightening techniques, we also implement specialized methods for tightening of McCormick relaxations. We present the algorithmic framework of MAiNGO along with computational applications to flowsheet optimization problems and hybrid mechanistic/data-driven models including artificial neural networks. Finally, we shortly introduce the interface and extension possibilities for the end-user planned for the open-source version.

■ MC-50

Monday, 12:30-14:00 - Mason Hayes & Curran

Various methodologies for OM/Marketing interface

Stream: Operations/Marketing Interface
Invited session
Chair: *Greet Vanden Berghe*

1 - Machine Learning Based Diving for Mixed Integer Programming: Decision Trees

Haroldo Santos, Samuel Brito, Greet Vanden Berghe

Given a Mixed-Integer Program P with n variables and m constraints, a diving is sequence of variable fixations. If successful, a diving can produce an integer feasible solution in at most n steps. For a fractional solution, there are several strategies reported in the literature for selecting the next fractional variable to be fixed to an integer value, considering different criteria such as fractional part, pseudocosts and occurrence in different constraints. In this work we explore the use of machine learning to, at each fractional solution, decide the the next strategy to proceed, producing an adaptive algorithm. Considering a set of problem features and relaxed solution features, decision trees are built to guide the diving procedure. One major advantage of decision trees over other machine learning techniques is that, for trees with limited depth, the next strategy can be selected in constant time. Promising computational results were obtained and comparisons with other diving strategies and with the feasibility pump heuristic are presented.

2 - Machine Learning approach for Data Centers Modeling and Optimization

Kateryna Mishchenko, Winston Garcia Gabin

Data centers (DC) are facilities equipped with special means to manage digital data. A need for such services is drastically growing, and as energy consumption in DC in the world is around 3.5% of the global electricity produced, the problem of energy saving is significant. Power optimization of data centers is based on underlying models for DC geometry, power distribution, etc. These models are meant for optimization and control and can be created using CFD approach, first principle modeling or numerical methods. CFD and first principle models are extremely computational costly and cannot be applied in real time operation.This paper presents a generic data driven approach to model and optimize power consumption in DC. The numerical models are created using machine learning.At first, there are created numerical models using the experimental design based on correlation tests. Then, artificial neural network models are developed and trained using real data. Such models are used to minimize the power consumption by means of nonlinear optimization. The results of numerical experiments confirm a high accuracy of the ANN approach, a modeling error being 3%. There were evaluated several nonlinear optimization problems based on these models. Power optimization was shown to possess a good performance with an energy saving potential of 20%. This approach implemented in ABB Ability^{TM} Data Center Automation solution allows to manage the complex energy and operational needs of DC.

3 - Inventory Systems with Stochastic and Batch Demand: Matrix Analytic Approaches

Walid Nasr

A main challenge in the modeling of inventory systems is formulating sufficiently detailed mathematical models which closely approximate the stochastic components of the system. Accounting for a larger number of the stochastic components increases the validity and accuracy of the model, but can significantly add to the computational complexity and intractability involved in analyzing the model. This motivates the use of Markovian Processes to capture the stochastic behavior of the demand process. This is a result of the well-established flexibility of Markovian processes in capturing key descriptors of point processes which include high variability, time-dependency, inter-arrival auto-correlation, and batch arrivals. This work presents computational frameworks to calculate the performance measures of continuous review inventory systems with Markovian demand. The computational framework is based on the state-representations of the inventory systems. Compact matrix representations are presented for the steady state solution of the inventory performance measures. The transient and non-stationary behavior of the inventory system is obtained from the numerical integration of the corresponding Kolmogorov Forward Equations.

4 - Online algorithms for Display Ads problem with two input models
Gwang Kim, Hyunwoo Kim, Ilkyeong Moon

Online bipartite matching is an online version of the bipartite matching problem in which one set of nodes is known in advance whereas the other set arrives online, one node at a time. Internet-based companies use an online bipartite matching problem and its generalizations when they deal with online advertising assignment. The problem can be interpreted as finding an optimal matching between the advertisements and ad slots. This paper considers Display Ads that is a generalization of the edge-weighted and capacitated online bipartite matching problem. In the existing literature, 'free disposal' property, in which an advertisement is assigned more than its capacity, is allowed for the problem to be tractable. Nevertheless, the solution seems unrealistic, and it could undermine the fairness between advertisers. The ultimate goal of this paper is to seek an optimal matching in which the total weight of matched edges is maximized while 'free disposal' is excluded. Thus, we analyze two online input models, based on the adversarial and probabilistic orders, to the problem. In the former order, deterministic algorithms are presented to show good competitive ratios. In the latter order, online algorithms with stochastic information are proposed to show good performances through numerical experiments.

■ MC-51

Monday, 12:30-14:00 - William Fry

Real Options: Theory

Stream: Optimal Control Theory and Applications
Invited session
Chair: Elmar Lukas

1 - Finite project life and (in)finite options duration: Effect on timing and size of capacity investment
Anne Balter, Kuno Huisman, Peter Kort

The literature on real investment in general departs from two assumptions. First, it is assumed that the project length is infinite, i.e. the firm produces forever after the investment has been undertaken. Second, the option to invest exists forever. This paper relaxes both assumptions. In a monopoly setting we find that, in case the inverse demand function linearly depends on a Geometric Brownian Motion process, a reduction of the project length delays the investment time whereas the investment size is not affected. Having a finite life of the investment option, caused for instance by technological progress making the product obsolete, accelerates investment whereas the investment size is reduced. We also investigate the effect of relaxing these two assumptions on the investment decisions of firms in a duopoly setting.

2 - Risk sensitive utility indifference pricing of real options under fixed transaction costs
Pavel Gapeev

We study the problems of risk sensitive utility indifference pricing for real options with fixed transaction costs in the classical model of a financial market with two tradable assets. Assume that the investors trading in the market must pay transaction costs equal to a fixed fraction of the entire portfolio wealth each time they trade. The objective is to maximise the asymptotic (risk null and risk adjusted) exponential growth rates based on the expected logarithmic or power utility of the difference between the terminal portfolio wealth and a certain amount of the option payoffs. It is shown that the optimal trading policy keeps the number of shares held in the assets unchanged between the transactions. In order to determine the optimal trading times and sizes, we reduce the initial problems to the appropriate (discounted) time-inhomogeneous optimal stopping problems for a one-dimensional diffusion process representing the fraction of the portfolio wealth held by the investor in the risky asset. The optimal trading and exercise times are proved to be the first times at which the risky fraction process exits certain regions restricted by two time-dependent boundaries. Then, certain amounts of assets should be bought or sold or the options should be exercised whenever the risky fraction process hits either the lower or the upper time-dependent curve. We illustrate these results on the examples of real asset-or-nothing options for which we obtain solutions in a closed form.

3 - Revenue-Enhancing Pre-Investments under Uncertainty
Tord Olsen, Verena Hagspiel

Models of investment under uncertainty mostly concern the firm's stochastic environment as exogenously given and subject to constant characteristics. We consider a firm that can sequentially invest to alter the growth rate of a project through a revenue-enhancing pre-investment activity prior to entering a new market, both when the change is fixed and when the magnitude of the change can be optimally chosen by the firm. We find that this incentivises the firm to invest early in revenue-enhancing activities, and then wait to invest to enter the market. There is both an option value of waiting that delays investment in revenue-enhancing activities, as well as an accelerating effect from the change in growth rate. The overall effect on the investment thresholds from increased uncertainty is ambiguous. Which effect dominates is dependent on both the cost parameters and the magnitude of the change in the rate of growth. When the firm can optimally choose the amount of the revenue-enhancing activity, we find that the firm invests more in these activities when uncertainty is higher, but the effect of uncertainty can still be ambiguous. When the marginal cost of the activity increases, the firm both delays the investment and undertakes less revenue-enhancement, but the overall amount spent increases. We conclude that increasing the drift through revenue-enhancing pre-investments is very attractive for the firm, and that this affects the firm's optimal investment strategy.

4 - Dynamic Market Entry in Oligopolistic Industries under Uncertainty: The Choice between Make or Buy
Elmar Lukas, Peter M. Kort, Andreas Welling

We extend the literature on market entry timing under uncertainty by accounting for the entrant's choice between greenfield investment and Merger & Acquisitions (M&A) with a suitable incumbent in the shadow of outside options and competing coalitions. By means of an oligopolistic model we derive analytical solutions for the optimal coalitions, industry characteristics, entry timing and M&A terms. The results indicate that entry timing becomes non-monotonic due to the entry mode choice. In particular, less uncertain and highly uncertain industries can exhibit delayed entry by means of M&A while for industries with intermediate levels of uncertainty entry timing can occur sooner with greenfield investment as the preferred choice. With respect to the target selection mechanism we find that (less) technological advanced foreign entrants prefer to enter by means of greenfield (merger with one of the incumbents). As uncertainty increases, however, (less) technological advanced foreign entrants prefer to merger with the weaker incumbent (local champion).

Monday, 14:30-16:00

■ MD-01

Monday, 14:30-16:00 - O'Reilly Hall

Nico Vandaele

Stream: Tutorials
Tutorial session
Chair: Joel Joris Van de Klundert

1 - Humanitarian Operations Modeling at the Interplay of Relief and Development
Nico Vandaele

In this tutorial we explore a personal view on how OR modeling can be helpful in supporting humanitarian and development decision making. We rely on the application field of immunization to illustrate our findings. Immunization systems have to cope both with prevention (as part of development) as well as with outbreaks (as part of disaster relief).

The starting point is a user-centered view; in this case a patient/child/population needs to be immunized. This led us to a five step approach, encapsulating the modeling of the problem setting. It is composed of (1) stakeholder analysis and system definition, (2) key performance indicators derivation, (3) modelling and scenario generation, (4) scenario ranking and (5) implementation. This baseline allows for complementary OR techniques and modeling approaches to be deployed. Recent literature reviews reveal multiple opportunities for research.

Relevance, resilience, sustainability and technological evolutions enforce us to opt for an interdisciplinary approach. Many of the insights from the immunization field are useful for other fields of decision support.

■ MD-02

Monday, 14:30-16:00 - Moore Auditorium

EJOR: policy, facts and highlights

Stream: EURO Journals
Tutorial session
Chair: Roman Slowinski

1 - Inventory rebalancing and vehicle routing in bike sharing systems
Willem-Jan van Hoeve, Jasper Schuijbroek, Robert Hampshire

Bike sharing systems have been installed in many cities around the world and are increasing in popularity. A major operational cost driver in these systems is rebalancing the bikes over time such that the appropriate number of bikes and open docks are available to users. We combine two aspects that were previously handled separately in the literature: determining service level requirements at each bike sharing station, and designing (near-)optimal vehicle routes to rebalance the inventory. Since finding provably optimal solutions is practically intractable, we propose a cluster-first route-second heuristic, in which a polynomial-size Clustering Problem simultaneously considers the service level feasibility and approximate routing costs. Extensive computational results on real-world data from Hubway (Boston, MA) and Capital Bikeshare (Washington, DC) are provided, which show that our heuristic outperforms a pure mixed-integer programming formulation and a constraint programming approach.

This work was published in European Journal of Operational Research (2017).

2 - Humanitarian logistics network design under mixed uncertainty: A narrative of an EJOR paper and its impact
Afshin Mansouri, S. Ali Torabi, Saeideh Tofighi

In this talk, we present a summary of our paper published in EJOR 250 (2016) 239-250 along with its background and impact. The paper is one of several outputs resulted from a long-term collaboration between Brunel University London and the University of Tehran, started from an ESRC-funded project in 2010. Motivated by the need for designing a relief network in Tehran in preparation for earthquakes, in this paper we addressed a two-echelon humanitarian logistics network design problem involving multiple central warehouses (CWs) and local distribution centres (LDCs) and developed a novel two-stage scenario-based possibilistic-stochastic programming (SBPSP) approach. During the first stage, the locations of CWs and LDCs are determined along with inventory levels of the prepositioned relief items. In the second stage, a relief distribution plan is developed based on a range of disaster scenarios. A tailored differential evolution algorithm is developed to find good enough solutions in a reasonable time. Computational results using real data revealed promising performance of the SBPSP model benchmarked against the existing relief network in Tehran. Subsequently, we disseminated our findings to local authorities and relief organisations in Iran that raised their awareness about suitable supply strategies. As a result, they started changing their procurement practice by adopting contractual agreements with suppliers to increase reliability of their response at reduced cost.

3 - Policy and facts about the European Journal of Operational Research (EJOR)
Roman Slowinski, Emanuele Borgonovo, Robert Dyson, José Fernando Oliveira, Steffen Rebennack, Ruud Teunter

The session will start with two presentations done by authors of representative and highly cited papers published recently in EJOR. Some further research developments and practical implications that followed these publications will be given by these authors. Then, the editors of EJOR will explain their editorial policy, and will give some current characteristics of the journal. They will also describe their approach to evaluation and selection of articles, and will point out topics of OR which recently raised the highest interest. In the last part of the session, the editors will answer some general questions from the audience.

■ MD-03

Monday, 14:30-16:00 - Q106

From Data to Decisions. The challenges of the digitalization era

Stream: Practice of OR (Making an Impact)
Tutorial session
Chair: Matteo Pozzi

1 - From Data to Decisions. The challenges of the digitalization era
Raffaele Maccioni

It is not always so easy to take the best decisions, both strategic, like to redesign the supply chain, or operative like to deliver goods at min costs, or to define prices and promotions. Even more, sometimes it is not so clear what "best" really means. This is also true for the solution that has been awarded by Informs as a finalist of the Franz Edelman Award. ACT Operations Research provides an inspiring view on what it takes to develop and implement "deep-analytical" solutions.

■ MD-05

Monday, 14:30-16:00 - A003

Special OR Aspects in Water and Energy Management

Stream: OR in Water and Hydro Energy Management
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Olabode Adewoye*

1 - Improving Resilience of Reservoir Operation in the Context of Watercourse Regulation in Finland
Jyri Mustajoki, Mika Marttunen

Resilience management aims to increase the ability of the system to respond to adverse events. In this study, we develop and apply a systematic approach based on the resilience matrix of Linkov et al. (Environ Sci Technol 47: 10108-10110, 2013) for improving the resilience of the decision making process related to reservoir (or lake) regulation in Finland. Our main objectives are two-fold. First, we aim to provide support for the reservoir operators in their work for identifying the possible threats and actions to diminish their consequences. Second, we study the applicability of the resilience matrix approach in a quite specifically defined operational process, as most of the earlier applications have focused on a more general context. Our resilience matrix was developed in close co-operation with the reservoir operators and supervisors of the water course regulation projects by means of two workshops and a survey. For the practical application of the matrix, we created an evaluation form for assessing the resilience of a single dam operation process and for evaluating the cost-efficiency of the actions identified to improve the resilience. We tested the approach on a dam controlling the water level of a middle-sized lake, where it proved to be a competent way to systematically assess resilience.

2 - Fuzzy FMECA Risk Analysis of Hydropower Dams: a Case Study in Brazil
Flavio Sohler, Jose Roberto Ribas

When applying the traditional Failure Mode, Effects and Criticality Analysis (FMECA) for dam risk assessment, the analyst may consider including a fuzzy expert system in the evaluation. The upside of the fuzzification is that it enables to add a measure of inaccuracy in the three factors - occurrence, severity and detectability, incorporating the imprecision into the process and allowing a better analysis of the possible choices. The adoption of an expert system by means of fuzzy rule base combines the linguistic terms and logic operators triggering the consequent risk categories. The defuzzification converts fuzzy numbers into a single crisp score with the same Risk Priority Number (RPN) scale as of the traditional method. The downside of the proposed method is the inability of the defuzzified RPN to monotonically increase with the one provided by the traditional FMECA method, due to the small number of linguistic terms adopted in the case study. The method was applied to the Simplicio Dam System, a 305,7 MW hydropower plant built in the Southeastern Brazilian region. It is concluded that fuzzy logic provides an enhancement on the perspective of consistency and reliability of the FMECA results. The introduction of an expert system allows the RPN to be aligned with the rational expectations, representing one important contribution for monitoring the risks associated with the relevant technical features, as we concluded through the case study.

3 - Optimizing Energy Efficiency: White Certificate Evaluations
Irem Duzdar Argun, Gulgun Kayakutlu, Neslihan Ozgozen

Energy efficiency(EE) and saving studies are in important topics of last era to solve the ecological and external independence affairs.EE means both decreasing production costs in industry and cheaper new energy sources.The results of EE in production industry, lower energy costs, then more competition power with energy selling countries.Effective energy consumption is the easiest way to stop and manage increases at energy bills.Energy costs can be decreased by improved technologies, better management and organization.White certificate(WC) is a good market based instrument to promote EE studies.Governments carry on energy policies with the support of state monopolies, by application of regulations, laws, etc. to increase efficiency.To obtain a certificate, an energy saving project or energy efficiency consulting is required.EU energy policies are trying to develop renewable energy consumption together with promoting EE studies.Energy efficiency policies motivate the economy, supply security, public and environmental health for EU Members.White certificate is worthwhile in policy instruments used to achieve EE policies.WC implement may be effective to achieve 20% energy efficiency, objective of Turkey for 2023. Here, the energy status and efficiency potential of Turkey will be discussed first. EE and WC are described, Turkey's efficiency policies and WC applications analysed.In this study a model is prepared a model to maximize energy saving and WC applications.

4 - The unit commitment problem: a mixed integer coded genetic algorithm based approach
Tolga Karabas, Sedef Meral
Unit commitment(UC) is one of the essential activities in power systems planning and operation that comprises two decisions: scheduling of on/off states of electricity generating units and their dispatching over the planning horizon. The objective is the minimization of total operating costs -fuel and startup costs-, while meeting the forecasted load requirements, and satisfying several operational and technical constraints. Some of these constraints are initial status restriction of each unit, minimum up and down times, capacity and generation limits, limited ramp rate, power balance and spinning reserve constraints. UCP is a mixed integer, non-linear and combinatorial problem, making it difficult to develop any rigorous optimization method for a real-size system. Hence, we intend to develop a Genetic Algorithm to obtain an optimal/near-optimal for the UC problem. While doing so, scheduling of on/off status of generating units in each period is handled by the genetic operators. Nevertheless, dispatching decisions related to power generation levels of committed units in each period are made by the Lambda Iteration Method. The main difficulty in the genetic algorithm for the UCP is it has several constraints -both continuous and binary types. Thus, we have developed a mixed-integer coding scheme that can handle these constraints. Our approach can provide satisfactorily good schedules and power generation levels for large scale power systems in a reasonable computation time.

■ MD-06

Monday, 14:30-16:00 - A004

Assessment of sustainable energy systems

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: *Jutta Geldermann*
Chair: *Marcel Dumeier*

1 - Modeling the Role of Combined Heat and Power in the European Electricity Market from a System Dynamics Perspective
Siamak Sheykhha, Reinhard Madlener
Combined Heat and Power (Cogeneration) is an energy-efficient technology option that enables CO2 emission reductions. We study the deployment of CHP in the European electricity market with HECTOR, an advanced bottom-up energy system model. We simulate the electricity market of 28 European countries on an hourly basis until 2050 from a system dynamics (SD) perspective, revealing results for dispatch and future investments. Based on technology-specific assumptions, CHP plants are modeled in two different ways: simple (backpressure mode) and complex (condensing mode) operation. The results from both modeling approaches are compared with each other. Besides the implementation of more advanced CHP technology in HECTOR, the modeling of CHP on an extended geographical area such as Europe enables a comprehensive analysis of how CHP affects renewable

energy and flexibility options deployment. We also study the impact of gas price changes on future investments in CHP plants. To this end, we define different scenarios to assess the implications of different CHP modeling methods on CHP plant investment, carbon emission mitigation, and total system costs.

2 - Optimal capacity adjustments in electricity market models - an iterative approach based on operational margins and the relevant supply stack
Robin Leisen, Benjamin Böcker, Christoph Weber

The modelling of energy systems often has to balance two aspects. On the one side, models aim at describing different aspects in detail, e.g. operation restrictions of power plants, CHP, grid restrictions etc. On the other side, models aim at the analysis of long-term developments in future electricity markets. Such models usually abstract on a higher level and have a lower level of detail. When focusing on one of the two aspects, models can be solved in a reasonable time. In order to combine both aspects in one model we use a problem-specific iterative approach. A detailed system model is linked to iterative adjustments of investments. This is based on a subgradient method of optimization frequently used in optimization. The approach can be described as a detailed dispatch model with adjustments towards an investment model. The approach reflects the effects of investment and disinvestment decisions on market prices (and thus on further corresponding decisions). The results show that the algorithm is quite efficient for a stylized model. For a larger model, interim results suggested that the performance could be further improved if the algorithm would be adjusted to cope differently with various starting situations (overcapacities vs. additional demand vs. shifting between technologies or locations). Nevertheless, with the developed methodology, a considerably improved understanding of the drivers and the dynamics of iterative capacity adjustments has been achieved.

3 - Multi-Period Multi-Criteria Evaluation of the Transition of Power Generation Systems
Tobias Witt, Jutta Geldermann

Energy scenarios describe possible future states or developments of energy systems, and are often used to provide orientation for strategic decision making in the energy sector or in energy policy, e.g., for planning the energy transition towards renewable energy technologies. In this context, multiple conflicting criteria, e.g., CO2-emissions and system costs need to be considered. Hence, Multi-Criteria Decision Analysis (MCDA) can support drawing conclusions from energy scenarios. However, as energy scenarios typically look several decades into the future, there are time-related challenges for providing adequate decision support: Today's decisions can lead to path dependencies, uncertainties associated with the input parameters and results of energy scenarios increase significantly over time, and the preferences of stakeholders may vary over time. We present a Multi-Period Multi-Criteria approach for the evaluation of transition pathways, which allows addressing these challenges. The approach is based on the outranking method PROMETHEE and consists of a three-phase procedure: In the first phase, the performance scores of the alternatives are calculated for each period. In the second phase, the alternatives are evaluated with PROMETHEE II in each period, and in the third phase, the evaluations of alternatives are aggregated along transition paths. As an example, the method is applied for planning the transition of the power generation system in Lower Saxony, Germany.

4 - Simulation and optimization model for the evaluation of the contribution of electric mobility to a regenerative power supply
Marcel Dumeier, Jutta Geldermann

Battery electric vehicles are to play a decisive role in the mobility of the future. A greater diffusion of these vehicles is expected to have an impact on the electricity demand, for instance by creating demand peaks in the evening hours. In Germany, the electricity demand of these vehicles will be met by a volatile electricity production that is expected to come from regenerative energy sources such as wind and solar. In order to distribute the loads arising from the charging of the vehicles in a power generation-oriented manner, a suitable charging infrastructure and supplementary charge management are required. This also results in a better utilization of electricity generated from re-generative sources. Thus, we propose a decision support model for a techno-economic assessment of the charging infrastructure. The mobility behavior of individuals is analyzed within a simulation model. Subsequently, a linear optimization model is used to optimize the charge of the individual vehicles. The aim of the decision support model is to analyze the load shift resulting from the charging in accordance to the volatile power generation. The combination of the simulation and optimization model enables the investigation and evaluation of different charging and expansion strategies of the charging infrastructure.

■ MD-07

Monday, 14:30-16:00 - A007

Stochastic Modeling and Simulation in Engineering, Management and Science 2

Stream: Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: *Nina Kajiji*
Chair: *Gerhard-Wilhelm Weber*

1 - Digital Twin for Next Generation Ports
Ek Peng Chew

We present the digital twin platform for Next Generation Ports. The digital twin is a digital manifestation of the physical systems and it has the ability to assist in the designing, planning and operations of the port systems. The platform is based on the object oriented Discrete Event Simulation modelling framework - O2DES.Net. This platform is not only able to evaluate a system but has the ability to search for optimal or good enough solutions as it can be integrated with optimization methods. Furthermore, for the digital twin to assist in real time port operations, it will need to embed analytics and learning engine to replace the optimization model as simulation optimization methods can be computationally expensive in time. The idea is to learn from optimal results offline by solving the optimization model using many different scenarios and then derive simple policies to replace the optimization model. The advantage of using the digital twin is the data learning does not only come from historical data but also from new data or scenarios generated by the digital twin. Application examples will be demonstrated and discussed.

2 - Long term (military) manpower planning: a WiP custom tool
Johan Van Kerckhoven, Oussama Mazari Abdessameud, Filip Van Utterbeeck

Proper HR planning is vital to the smooth operation (and survival) of any kind of organization, including military organizations. This can be short term planning as in scheduling employees, or long term planning, such as hiring and promotion strategies, which is the focus of this work. These long term planning decisions are too important to be left solely to the managers' "gut feeling". Instead, they can choose to employ one or several mathematical models to provide valuable insights towards making appropriate decisions.

Here we present the current state of a discrete event simulation tool/engine which we are developing in Julia - using the SimJulia package - to assist with long term manpower management of our organization. Although this tool is inspired by one particular case, our ultimate goal is to make this tool as generic and configurable as possible, while also being easy to use.

We will present the rationale behind our chosen approach, and give some insight on how the tool handles the different HR aspects of the system. We will also highlight its current capabilities, and elaborate on how this simulation engine can be used to drive one or more (heuristics based) optimization routines to find an optimal solution to a particular planning problem. We will offer a short roadmap for the way ahead, highlight the features that are still in development, and the points where the tool requires improvement. Finally, if time permits, a short demo will be provided.

3 - Improving Healthcare Wait-Times - Using Discrete Event Simulation to Enable Frontline Redesign
Peter ONeill, Ian Gibson, Jo Egan

This paper sets out an approach to improving healthcare delivery using discrete event simulation as an input to the wider challenge of reducing wait-times. The modelling was undertaken to develop and test patient flows, and new processes for a clinic within a large community health network. Managers of the project wished to identify the potential bottlenecks in the design, develop solutions and plan for implementation. We demonstrate the capability of the approach to identify potential bottlenecks in the facility's designed patient flows.

The approach uses the theory of constraints and Balridge framework to consider the availability of resources (i.e. clinicians, equipment and space), and analyse the potential effects of resultant changes on the whole system. The method enables options to better match demand for services with the resources required to deliver them. The approach included developing process models based on our designed components that can be combined quickly to model the patient pathway of a dental clinic. The simulation included a capacity to create libraries for utilization in the models.

Our results demonstrate that simulation could improve access to healthcare services; reduce waiting; improve safety; reduce unscheduled overtime; improve job design; and reduce capital and operating costs in healthcare systems by more than 20%. We also predict the proposed method can improve the success rate of change management projects within healthcare clinics.

4 - Quantifying Input Modelling Error in Stochastic Simulation
Lucy Morgan

Stochastic simulation is a tool used to aid decision making. It allows practitioners to analyse and experiment with systems driven by random processes. The conclusions drawn from simulation experiments are conditional on the input models that drive them. Typically, these input models, represented by probability distributions or processes, are estimated using observations collected from the real-world system using statistical methods such as maximum likelihood estimation. When this is the case uncertainty arises in the estimated input models due to the fact that only a finite number of observations can be collected. This error propagates to the simulation performance measures of interest; we call this error the error due to input modelling. As the amount of input data increases the error in the input models decreases, so less error passes to the simulation output, but they are never perfectly correct. In experiments where constraints on time and money limit the number of observations collected from a system, the error in the input models can be substantial. In this talk, we present recent contributions to the field of input modelling error quantification including methods for quantifying the variance and bias caused by input modelling. We illustrate these methods on a model of the NHS 111 health care call centre system.

■ MD-08

Monday, 14:30-16:00 - A008

Practice-based humanitarian OR

Stream: OR in Humanitarian Applications
Invited session
Chair: Alfonso Pedraza-Martinez

1 - Scenarios generation for a decision aid model for strategic facility location and tactical prepositioning of first relief aid
Begoña Vitoriano, Adán Rodriguez, M. Teresa Ortuno

A model for strategic facility location and tactical resource prepositioning is being developed for a multi-period stochastic problem to manage natural disaster's preparedness. Strategic decisions are focused on warehouses location and sizing, while tactical prepositioning relates on yearly planning. Further, operational decisions are taken into account in the model for different scenarios considered. The framework is developing countries, considering that relief aid should be enough to support the affected people until international relief will arrive.

The model considers uncertainty on different disaster scenarios. These scenarios will be characterized by the type of disaster, the area impacted, the amount needed for general relief and for homeless people, damage on infrastructures, etc. Besides, it must be taken into account that they will be the input of an optimisation model, determining its dimensions. A test case based on real data of Mozambique will be presented.

2 - Dynamic Lexicographical Goal Programming Optimization in Evacuation and Commodity Distribution
M. Teresa Ortuno, Inmaculada Flores, Gregorio Tirado, Begoña Vitoriano

In the recent past, the huge number of natural and human-made disasters and their consequences have alarmed the world population. This paper deals with the evacuation plan and the distribution of supplies for humanitarian aid after the occurrence of a disaster. A multicriteria mixed integer model is introduced to evacuate the population from affected to safe areas, as well as to guide the geographical location of resources according to the needs of the evacuated population.

People from the affected areas have been classified based on their priority to be evacuated. Supplies have been classified as consumable and non-consumable. Both people and supplies will be arriving over time (as new people to evacuate or as donations arriving, respectively).

A Dynamic lexicographical Goal Programming Model is introduced. The first level is concerned with determining the maximum number of people that can be evacuated according to the parameters of the particular case at hand. The second level corresponds to minimizing the total time required to evacuate the critical population. Finally, the third level minimizes a weighted combination of goal deviations involving criteria related to cost, time to evacuate all affected people and coverage of basic commodities by evacuees.

3 - Optimizing Sample Referral Networks for HIV Early Infant Diagnosis
Michal Tzur, Reut Noham, Dan Yamin

The AIDS epidemic, caused by HIV, continues to be a major global public health concern, despite the substantial advances in the scientific understanding of the virus, its prevention and treatment. The vast majority of people living with HIV (PLHIV) are located in low- and middle-income countries, with an estimated 25.5 million living in sub-Saharan Africa. In Tanzania, there are 1.5 million PLHIV, accounting for 5.4% of the population. During 2017, 11,000 new cases of infections and 6,000 deaths among children were reported there. Early diagnosis among infants and early initiation of treatment are essential for HIV elimination and currently takes a key role in the WHO global targets. We introduce and analyze the sample referral design problem based on a case study from Tanzania. The goal is to design a supply chain network for delivering HIV test samples in an environment where performing the tests requires resources that are scarce and costly. Using queueing theory, we present an analytical framework to evaluate the waiting time distribution of a sample and incorporate it in a mathematical model. The model is utilized to minimize the expected number of infants who die from AIDS due to delays in the return of results by restructuring the sample referral network. We demonstrate the applicability of our model for the case of Tanzania and show that, compared to the current strategy, an efficient design has the potential to save the lives of 75 infants, on average, annually.

4 - Funding-Based Competition in Humanitarian Operations
Alfonso Pedraza-Martinez, Arian Aflaki

We study the optimal funding strategy of a Humanitarian Organization (HO) in the presence of control-seeking donors. We find that a monopolist HO can ask for control over donations to improve its operational efficiency. In contrast, an HO facing competition for funding has limited ability to collect non-earmarked donations. Our work contributes to the growing body of literature on funding in humanitarian operations management.

■ MD-09

Monday, 14:30-16:00 - B006

DEA applications in Agriculture and Food

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Magdalena Kapelko

1 - Combining nonparametric efficiency measures and parametric inference to assess technological progress for the Brazilian agriculture
Geraldo Souza, Eliane Gomes, Eliseu Alves, José Gasques

We analyze technical progress in the Brazilian agriculture in the period 1976-2016. Output is production value and inputs are expenses on land, labor, and other inputs. Data Envelopment Analysis (DEA) measures are used to capture technological progress via efficiency analysis. Filtering the data with a moving average and fractional regression we identify four periods with distinct behavior of technical efficiency under constant or decreasing returns to scale. From 1976 to 1988 and from 1996 to 2007 technical efficiency decreases at statistically significant rates of -1.74% and -0.26% respectively. From 1989 to 1995 and from 2008 to 2016 efficiency increases at statistically significant rates of 1.53% and 1.75% respectively. Efficiency of input use varies in these periods and is computed as a byproduct of the DEA analysis. We observe a more efficient usage of land and other inputs. A parametric fit using adjusted efficient inputs indicate the relative elasticities of 40.5%, 38.5% and 21.0% for other inputs, land and labor, respectively. Technological progress is constant in the first period, increases at a rate of 11.0% in the second period, at 6.5% and 9.8% in the subsequent periods. Technological inputs are statistically significantly influential on total factor productivity as indicated by an infinite distributed lag model. The long run elasticity effect is 39.5%. The effect of investments (public) in agricultural research has a significant elasticity of 0.835.

2 - Structural change and aggregate efficiency in Lithuanian dairy farms: An application of the Olley-Pakes decomposition
Tomas Balezentis, Giannis Karagiannis

In this paper, we establish a framework based on data envelopment analysis (DEA) and Olley-Pakes decomposition to look into the patterns of the aggregate efficiency along time. The proposed approach allows identifying the major groups of decision making units contributing to the aggregate efficiency change. We also suggest identifying influential peers in order to gain more insights into possible development strategies within a sector. The empirical application focuses on the specialist dairy farms in Lithuania. The farm-level data cover the period of 2004-2016. The results indicate the presence of structural changes and the resulting shifts in the aggregate productivity. Based on the results of the decomposition of the covariance term and identification of the influential peers, the two models can be followed by Lithuanian dairy farms, namely "pure" family farms with lower operation scale and large farms involving hired labour.

3 - The effect of subsidies on agricultural efficiency in the EU
Lukas Fryd, Ondřej Sokol

One of the biggest debate in the European Union is connected with the agricultural policy and related subsidies. We focus on the evaluation of the effect of subsidies in the agriculture business. We focus on the microeconomics panel data from the FADN agency which collects data from a sample of EU farms. Firstly, we measure the farm's efficiency with data envelopment analysis. We use various financial ratios such as liquidity ratios, profitability ratios, debt ratios, operating performance ratios, cash flow indicator ratios, etc. Secondly, due to the reason of hierarchical data structure, country, area, and farm size, we use a linear mixed model to evaluate the subsidizing effect on the farm's efficiency.

4 - The Relationship between Corporate Social Responsibility and Input- and Investment-Specific Dynamic Productivity Change in the US Food and Beverage Manufacturing Industry
Magdalena Kapelko, Alfons Oude Lansink, Encarna Guillamon-Saorin

This article examines the relationship between corporate social responsibility (CSR) and the dynamic productivity change of each input employed and investment undertaken in the US food and beverage manufacturing industry. Productivity change is assessed via a dynamic production approach using Data Envelopment Analysis. We compute input- and investment-specific dynamic Luenberger indicators and decompose them into the contributions of input- and investment-specific dynamic technical inefficiency and technological changes. We then relate these indicators to an overall and aspect-specific CSR measures (governance, environment, and social). The results suggest a negative relationship between the overall CSR and dynamic productivity change for investments, due to the negative relationship between dynamic technical inefficiency change for investments and CSR. We also find a negative association between overall CSR and dynamic technological change for costs, but a positive relation for dynamic technical inefficiency change for this input. The analysis of the relations between dynamic productivity change and individual CSR aspects show negative relations for dynamic productivity and inefficiency changes for investments with the environmental and governance aspects of CSR. Also, dynamic technological change for costs has a negative association with the governance dimension of CSR, while the social dimension of CSR has a positive association with dynamic inefficiency change for costs.

■ MD-10

Monday, 14:30-16:00 - H0.12

Robust Optimization : extensions of Gamma-robustness

Stream: Robust Optimization
Invited session
Chair: Laurent Alfandari

1 - Globalized Gamma-Robustness
Christina Büsing, Andreas Bärmann, Frauke Liers

Adding uncertainties into the decision process is an important task. In robust optimization, a solution is called optimal robust, if it is feasible for a given set of scenarios and minimizes the worst-case cost according to this scenario set. A scenario describes a certain setting or realization of the uncertain parameters. However, this approach neglects the existence of scenarios outside the scenario set. The behavior, e.g., the cost and feasibility, of a robust solution cannot be predicted.

In globalized robustness, introduced by Ben-Tal and Nemirovski, every scenario is extended by a specific relief term for the cost or the imposed constraints. This allows smoothening the behavior of the solution for a big and inhomogeneous scenario set. In this talk, we consider globalized robustness with combined polyhedral Gamma- scenarios sets and relief terms depending on the Gamma parameter. We start by considering the complexity of such a setting for standard combinatorial optimization problems like the shortest path problem. In a next step, will concentrate on deriving compact linear formulations for the globalized robust counterpart. The tractability of our formulations and the quality of the obtained solutions will be tested for uncertain variants of several combinatorial optimization problems.

2 - Robust optimization for non-linear impact of data variation

Laurent Alfandari, Juan Carlos Espinoza Garcia

We extend the Gamma-robustness approach proposed by Bertsimas and Sim for Linear Programs to the case of non-linear impact of parameter variation. The seminal work considered protection from infeasibility over the worst-case variation of coefficients in a constraint, this variation being controlled by an uncertainty budget called Gamma. When coefficients are non-linear functions of a parameter subject to uncertainty, we study a piecewise linear approximation of the function, and show that the subproblem of determining the worst-case variation can still be dualized despite the discrete structure of the piecewise linear function. We conduct numerical experiments on three different optimization problems with binary variables: a variant of Capital Budgeting where one selects a portfolio of projects minimizing the total investment subject to a given threshold on portfolio net present value (NPV), Generalized Assignment, and Knapsack problems. We analyze the trade-off between feasibility and objective value for the robust solution of the piecewise linear approximation compared to the nominal solution, and to a simpler binary approximation. We also investigate the impact of the number of pieces in the piecewise approximation. Despite this approximation, the robust solution reveals to remain feasible over the 6800 runs performed in our experiments, with an average deterioration of the objective value of only a few percents.

3 - Lagrangian duality for a class of two-stage robust problems

Agostinho Agra, Filipe Rodrigues, Erick Delage, Cristina Requejo

We consider a class of min-max two-stages robust problems which includes many practical Problems, such as lot-sizing problem under demand uncertainty where the production decisions are first-stage decisions and the inventory variables are adjustable to the demands. By considering a Lagrangian relaxation of the uncertainty set, we derive a tractable approximation. We relate the resulting dual Lagrangian approach to the classical dualization approach introduced by Bertsimas and Sim (2004) and to the exact min-max approach. Moreover, we show that the dual Lagrangian approach coincides with the affine approximation of the uncertainty set.

The dual Lagrangian approach is applied to a lot-sizing problem where demands are assumed to be uncertain and to belong to the well-known budget polytope introduced by Bertsimas and Sim (2003, 2004). Computational results are reported in order to compare this approach against the exact min-max approach introduced by Bienstock and Özbay (2008) and the dualization approach from Bertsimas and Thiele (2006), for a set of lot-sizing instances where additional practical aspects, such as setup costs, are considered.

4 - Optimal robust designs for accelerated failure time models with right censured observations

Raúl Martin-Martin, María Jesús Rivas-Lopez, Irene García Camacha Gutiérrez

Accelerated Failure Time (AFT) models are fairly commonly used in the field of manufacturing, but they are more and more frequent for modeling clinical trial data. These models are defined through the survival function of the time-to-event variable, T. This work deals with the construction of optimal robust designs for AFT models with the possibility that the acceleration factor (AF) is misspecified when the variance of T is known and the date are assumed to be subject to censoring. In particular, we allow the "true" (AF) to vary over a neighbourhood of possible functions, for some unknown perturbation function. We consider these functions lie in a contaminating space. Thus we cannot assess the efficiency of a design through the covariance matrix of the maximum likelihood estimator (MLE). In this case, the estimate is subject to both "bias error" due to the inadequacy of the model, as well as "variance error" due to sampling. We obtained the asymptotic mean squared error matrix (MSE) of the parameter estimates for right censored observations and methods for obtaining minimax designs, based on alphabetic criteria I- and D-optimality, are presented. In order to the asymptotic treatment we will assume that perturbation functions are of the order 1/root(n). Finally, a typical distribution in AFT, Log-Logistic distribution, was considered to apply the above results.

■ MD-11

Monday, 14:30-16:00 - H1.12

Calmness and Lipschitz properties in continuous optimization

Stream: Nonlinear Programming. Theory and Methods
Invited session
Chair: *Maria Josefa Cánovas*
Chair: *Juan Parra*

1 - A uniform approach to Hölder calmness of subdifferentials

Marco A. López-Cerdá, Gerry Beer, Maria Josefa Cánovas, Juan Parra

For finite-valued convex functions defined on the Euclidean space, we are interested in the set-valued mapping assigning to the pair formed by a function and a point the subdifferential of the function at this point. We present results which are uniform as they involve pairs of functions which are close to each other, but not necessarily around a nominal function. More precisely, we provide lower and upper estimates, in terms of Hausdorff excesses, of the subdifferential of one of such functions at a nominal point in terms of the subdifferential of nearby functions in a ball centered in such a point. In particular, the property of (1/2)-Hölder calmness of our mapping is establised under natural assumptions.

2 - Lipschitz lower semicontinuity properties for linear inequality systems and their moduli

Maria Jesús Gisbert Francés, Maria Josefa Cánovas, Rene Henrion, Juan Parra

This talk is focussed on the Lipschitz lower semicontinuity (Lipschitz-lsc, in brief) of the feasible set mapping for linear (finite and semi-infinite) inequality systems in three different perturbation frameworks: full, right-hand side (RHS), and left-hand side (LHS) perturbations. Inspired by previous works of D. Klatte (1985,1987), we introduce the Lipschitz lower semicontinuity-star (Lipschitz-lsc*, in brief), which constitutes an intermediate property between the Lipschitz-lsc and the well-known Aubin continuity. Roughly speaking, the Lipschitz lower semicontinuity properties measure the rate of local contraction (in a neighborhood of a given nominal solution) of the feasible set under data perturbations, while the Aubin property deals with the rate of local variation (contraction/expansion) of this set. We advance that all these properties (Lipschitz-lsc, Lipschitz-lsc*, and Aubin) are equivalent for the feasible set mapping when confined to the contexts of full or RHS perturbations. Going further, one of the main contributions of this work consists of proving that the corresponding moduli do coincide. Finally, we analyze the three properties under LHS perturbations, where notable differences arise.

3 - Calmness and Lipschitz moduli of uncertain linear inequality systems with the Hausdorff metric

Maria Josefa Cánovas, Rene Henrion, Marco A. López-Cerdá, Juan Parra

This talk deals with uncertain linear inequality systems whose uncertainty sets are nonempty closed subsets of the n-dimensional Euclidean space. The perturbation size of these uncertainty sets is measured by the (extended) Hausdorff distance. The initial aim of this work was to provide operative expressions for calmness constants, and their associated neighborhoods, for the feasible set mapping. Having this goal in mind, the talk introduces an appropriate indexation function which allows us to provide our aimed calmness constants through their counterparts in the setting of linear inequality systems with a fixed index set, where a wide background exists in the literature. As a second stage, an ongoing work about a new indexation strategy, which enables us to tackle the computation of the Lipschitz modulus, will be presented.

4 - A Farkas lemma approach to calmness of linear inequality systems
Juan Parra, Maria Josefa Cánovas, Nguyen Dinh, Dang Hai Long

We deal with the feasible set mapping of linear inequality systems under right-hand side perturbations. From a version of Farkas lemma for difference of convex functions, we derive an operative relationship between calmness constants for this mapping at a nominal solution and associated neighborhoods where such constants work. Illustrative examples are provided with the aim of showing how this approach allows us to compute the sharp Hoffman constant in specifics situations.

■ MD-12

Monday, 14:30-16:00 - H1.51

Topics in Combinatorial Optimization II

Stream: Combinatorial Optimization I
Invited session
Chair: *Silvano Martello*
Chair: *Paolo Toth*

1 - A bi-criteria approach to find shortest and maximally SRLG-disjoint path pairs - computational experiments
Marta Pascoal, João Clímaco, José Craveirinha

In a previous work an exact method was developed to find the efficient pairs of paths from an origin to a destination in a network with respect to the total cost of their arcs and the number of arc labels that they have in common. The method results from the combination of an algorithm which ranks paths by order of cost, a modification of the network that allows to compute paths which correspond to pairs of paths in the original structure, and a test for discarding the pairs of paths which are dominated. This method was applied to telecommunication network robust routing design, involving the calculation of a primary and a backup path between two nodes, to be used when the primary path is unavailable due to possible failures. The objective functions of the bi-criteria model, to be minimized, are the cost of the two paths and the number of common Shared Risk Link Groups (SRLGs) of their arcs, which represent the common failure risks assigned to the arcs, such that each risk corresponds to a label. We will review the algorithm and present computational tests for assessing its performance on logical networks constructed over reference network topologies, considering various distributions of random SRLG assignments.

2 - Exact solution of the Interval Min-Max Regret Knapsack Problem
Rosario Scatamacchia, Federico Della Croce

We consider the interval min-max regret knapsack problem, a generalization of the classical 0-1 knapsack problem where the profit of each item ranges between a minimum and a maximum value. A given assignment of the items profit levels defines a scenario which corresponds to a standard knapsack instance. The problem calls for finding a feasible solution that minimizes the maximum regret over all possible scenarios, where the regret represents the difference between the optimal solution value of a scenario and the value given by the selected solution. We propose an alternative bilevel programming reformulation of the problem with two agents, a leader and a follower, that operate to reach different objectives. The leader first chooses a feasible knapsack solution with the goal of minimizing the regret associated with his decision. Then, the follower solves to optimality the knapsack instance corresponding to the worst-case scenario induced by the leader's solution. We derive a new exact approach that exploits the structural presence of two decision levels and the expected features of an optimal solution of the follower's knapsack problem. Preliminary computational tests indicate that the proposed approach is competitive with the state-of-the-art algorithms in solving benchmark literature instances. Extended results will be presented at the conference.

3 - Scheduling multiple double-load cranes in steel slab yards
Jiyin Liu, Guodong Zhao, Lixin Tang

This paper studies a multiple double-load crane scheduling problem in steel slab yards. Consideration of multiple cranes and their double-load capability makes the scheduling problem more complex. This problem has not been studied previously. We first formulate the problem as a mixed integer linear programming model. A two-phase model-based heuristic is then proposed. To solve problems of large size, a pointer-based discrete differential evolution algorithm is used with a dynamic programming algorithm embedded for solving the one-crane subproblem for a fixed sequence of tasks. Real problems instances are collected from a steel company to test the performance of the solution methods. The experiment results show that the model can solve small problems optimally and the optimal solution greatly improves the schedule used in practice. The two-phase heuristic generates solutions not far from optimal, but it can only solve slightly larger problems. The differential evolution algorithm can solve large practical problems relatively quickly while its solution is better than the two-phase heuristic solution, demonstrating that it is effective and efficient and so suitable for practical use.

■ MD-13

Monday, 14:30-16:00 - H2.12

Discrete and Global Optimization IV

Stream: Discrete and Global Optimization
Invited session
Chair: *Jan van Vuuren*
Chair: *Gerhard-Wilhelm Weber*

1 - Computational geometry and the recommender problem
José Dulá, Marie-Laure Bougnol

We approach the problem of proximity in the user-based collaborative filtering recommender problem using computational geometry. Convex hulls of the data are used to identify like-minded peers which will be used to predict scores. We incorporate this idea in a recommendation procedure and compare the results with more conventional methods.

2 - Overlapping Community Detection based on Partioning Around Medoids
Leonidas Pitsoulis

In this talk we will present a novel method for finding overlapping communities in networks by detecting disjoint communities in the associated line graph through link partitioning and partitioning around medoids. Partitioning around medoids is done by employing a distance function defined on the set of nodes of the line graph. In the present work we consider the commute distance and amplified commute distance functions as distance functions. The performance of the proposed method is demonstrated by computational experiments on real life instances.

3 - Representation and quality of the answers, identified by digraphs, obtained in conditions of collaborative school learning.
Patricia Balderas

The main objective of this study is to identify the representation and quality of the answers obtained in conditions of collaborative school learning by high school students. The students' written answers were the source to construct digraphs that allowed identifying the representation and the quality of the answers when they are compared with a criterion (the response of the teacher). The analysis of the responses of 19 high school students, who worked individually guided by a learning material and the use of advanced calculators, to the item: "Evaluate the change that occurs in the independent variable when you move from the position occupied by point A (-3.0) to the position of point B (-2, -3), in the graph of the function y = x2 + 2x - 3. Explain your answer". The quality of the discursive response of 19 participants was good because 10 of them had an index higher than 0.543, although they were not located in the conceptual framework, due to the low conceptual structure and low quality in correspondence with the concepts and relationships contained in the criterion.

■ MD-14

Monday, 14:30-16:00 - H2.20

Computational Methods in Integer Programming

Stream: Mixed Integer Programming
Invited session
Chair: *Fabrizio Rossi*
Chair: *Stefano Smriglio*

1 - Multiple optimal solutions and pseudo-symmetry breaking inequalities
Stefano Smriglio, Christopher Muir, Jim Ostrowski, Fabrizio Rossi

Symmetric integer programs (IPs) are difficult to solve using traditional branch-and-cut algorithms. This is mainly due to the massive amount of identical solutions scattered in the search tree, which makes pruning subproblems harder. Enhanced branching methods have been developed to deal with this problem which partition optimal solutions into a (relatively) small number of sets and restrict the search to just unique representatives of each partition. The presence of multiple equivalent solutions is not an exclusive feature of symmetric IPs. Indeed, it typically shows up in hard instances of many combinatorial optimization problems even when these do not have large symmetry groups. We illustrate an attempt to extend the symmetry-exploiting paradigm to these problems. The idea is to define pseudo-orbits, that is, groups of variables which mimic the role of orbits in confining multiple equivalent solutions and selecting some representatives. Defining pseudo-orbits may require some 'art', so as to benefit from the (problem-specific) structure of equivalent solutions. We introduce the method in the context of the classical stable set problem, which represents a meaningful benchmark for the assessment of the approach. We experiment with a family of inequalities associated with such disjunctions, showing that these cut-off many equivalent solutions (while preserving at least one representative) and often reduce solution times.

2 - Computational experience with the Capacitated Facility Location problem
Fabrizio Rossi, Pasquale Avella, Maurizio Boccia, Sara Mattia

The Capacitated Facility Location problem (CFLP) is to open a set of facilities with capacity constraints, with the aim of satisfying at the minimum cost the demands of a set of clients. CFLP has been widely addressed in the literature. State of the art results have been obtained by embedding Benders decomposition into an enumeration scheme. Here we report on a computational experience with rank-1 disjunctive cuts. We embed the separation procedure for disjunctive cuts into a cut-and-branch scheme truncated at the root node. This results into a MIP heuristic with final gaps significantly smaller than those reported in the recent literature. We validate the approach over a set of challenging benchmark instances from the literature.

3 - Intensity Modulated Proton Therapy by Integer Programming
Francesca Marzi, Fabrizio Rossi, Stefano Smriglio, Filippo Mignosi

In the context of radiotherapy, Intensity Modulated Proton Therapy (IMPT) represents a state of the art method in terms of dose delivery. Planning IMPT amounts to decide the intensity, energy and position of beams in order to obtain the best compromise between the reaching of the prescribed dose on the target volumes (including tumors) and the sparing of dose in general and in critical organs. In practice, experts manually select a limited number of fields (or directions from which the beams are shooted), generally up to six typically three, and either optimise each field independently (single-field optimisation) or simultaneously (multi-field optimisation, MFO). Experts often make use of tools embedding MonteCarlo or analytical methods and optimisation algorithms, such as simulated annealing which take into account propagation patterns of radiation in tissues. We show that a simplified version of the problem belongs to the class NPOPTAS if NP not equal to P. Moreover, the proof of this result indicates that the hardness of an instance seems to increase with the number of unconnected target volumes. We then develop Mixed Integer Linear Programming models related to the Maximum Feasible Subsystem (MAX-FS) problem and experiment with them on a set of clinical data. We discuss different objective functions and show that this method allows for a significant increase of the number of fields in MFO and also for an automatic selections of fields, which may bring concrete benefits.

4 - Strengthening of Mixed Integer Linear Program Bounds using Variable Splitting
Jens Vinther Clausen, Stefan Ropke, Richard Lusby

Dantzig-Wolfe decomposition is a reformulation process that can be used to strengthen the linear programming relaxation of a mixed integer linear program by splitting the problem into smaller sub-problems in which the integrality constraints are enforced. Traditionally, the decomposition is limited to sub-problems without overlap in variables. Variable splitting, also sometimes referred to as lagrangian decomposition, is an extension of Dantzig-Wolfe decomposition that removes this limitation by "cloning" the overlapping variables. This talk presents our results of applying variable splitting to a number of problems. The achieved LP bounds are used in a branch and bound algorithm to achieve integer optimality and the performance is compared to that of a commercial solver. Some of the examined problems are the fixed cost transportation problem (FCTP) and the single commodity fixed charge network flow problem (SCFCNFP). Both of which are flow problems, in which the demand and supply of the vertices in a graph must be obeyed, minimizing a per unit of flow cost and an initial cost on the edges (the initial cost has to be payed if the edge is used in the solution). The experiments include examining how, different decompositions, adding cuts to the sub-problems, and to the master problem, affect the strength of the bounds and performance of the algorithm.

■ MD-15

Monday, 14:30-16:00 - H2.32

Mixed Integer Multiobjective Optimization

Stream: Multiobjective Continuous Optimization
Invited session
Chair: *Marianna De Santis*

1 - A Criterion Space Search Algorithm for Mixed Integer Linear Maximum Multiplicative Programs: A Multi-objective Optimization Approach
Hadi Charkhgard, Payman Ghasemi Saghand

We present a criterion space search algorithm, i.e., a mixed integer linear programming based algorithm, for a class of mixed integer optimization problems with a multi-linear objective function and linear constraints. This class of optimization problems has several applications in different fields of study in particular cooperative game theory. Although this class of optimization problems has only one objective function, it can be viewed as a special case of the problem of optimization over the set of efficient solutions in multi-objective optimization. We use this observation and develop an exact custom-built algorithm based on that. An extensive computational study demonstrates that the proposed algorithm significantly outperforms a commercial solver with or without linearization, i.e., by a factor of more than 10 on many instances.

2 - Mixed-Integer Nonlinear Multiobjective Optimization by Branching in the Pre-Image Space
Gabriele Eichfelder, Marianna De Santis, Julia Niebling, Stefan Rocktäschel

We propose a numerical method for solving multiobjective mixed-integer convex optimization problems. The algorithm determines a covering of the whole set of efficient solutions. The method uses a branch-and-bound strategy based on a partitioning of the feasible set in the pre-image space. For discarding, lower and upper bounds are used. Lower bounds are obtained by outer approximations of the non-dominated set of sub-problems. Those are obtained by using ideas from Benson's algorithm. Such outer approximations already turned out to be a valuable tool for solving continuous nonconvex multiobjective optimization problems. That approach is now transferred to handle also integrality constraints.

In contrast to criterion space methods, which are often limited to bi-objective problems, our approach can be generalized to an arbitrary number of objective functions. Moreover, by using the technique of convex underestimators, it can also be extended to problems with non-convex objective functions. However, it has its limitations in the number of variables which can be handled. First numerical results are presented.

3 - The Frontier Partitioner Algorithm: a Branch and Cut algorithm for Biobjective Integer Programming
Marianna De Santis, Giorgio Grani, Laura Palagi

We present an algorithm for finding the complete Pareto frontier of biobjective integer programming problems. The method is based on the solution of a finite number of integer programs, each of them returning a Pareto optimal point. The feasible sets of the integer programs are built from the original feasible set, by adding cuts that separate efficient solutions. Providing the existence of an oracle to solve suitably defined single objective integer subproblems, the algorithm can handle biobjective nonlinear integer problems, in particular biobjective convex quadratic integer optimization problems. Our numerical experience on a benchmark of biobjective integer linear programming instances shows the efficiency of the approach in comparison with existing state-of-the-art methods. Further experiments on biobjective integer quadratic programming instances are reported.

■ MD-16

Monday, 14:30-16:00 - Theatre A

Young researchers in CO

Stream: Combinatorial Optimization II
Invited session
Chair: *Martina Fischetti*
Chair: *Lavinia Amorosi*

1 - Traffic-dependent limited unfairness in a system optimum traffic assignment
Valentina Morandi, Enrico Angelelli, M. Grazia Speranza

The problem of finding, in traffic assignment, a compromise solution between system optimum and user equilibrium has been addressed by restricting a priori the set of eligible paths. However, when traffic flows on the road network, eligible paths could turn out to be more unfair than expected a priori. In this talk a mixed-integer linear programming (MILP) model is presented that embeds the computation of the level of unfairness experienced by users on road network and aims at minimizing the total travel time provided no user experiences an unfairness higher than a pre-defined level. Computational results show that the total travel time spent by users is very close to the minimum possible, that is the one obtained by the system optimum solution, while guaranteeing to each user a very low level of experienced unfairness. As the MILP model requires the a priori enumeration of all paths for each origin-destination pair, a heuristic algorithm is also proposed which is shown to generate high quality solutions.

2 - Bi-Criteria Mathematical Models for UAV Based Spatial Services Management
Lavinia Amorosi, Paolo Dell'Olmo

This talk faces two relevant Service Management Problems, namely the next generation 5G standard mobile broadband coverage problem and the good parcels distribution problem, which, due to the lack of infrastructures (antennas, roads, warehouses, ...) quite typical in rural areas, can be effectively supported by the adoption of Unmanned Aerial Vehicles (UAVs). See [1] for a survey on UAVs different civil usages and [2], [3] for recent applications of UAVs in the telecommunication sector. After a detailed description of the problems settings, necessary to define the practical limits of these solutions, we formalize a number of constraints for the use of UAVs which are common to both problems (UAVSs energy consumption, battery power of the recharging sites, etc...). Successively, we describe thoroughly the mathematical models for the two problems requiring the simultaneous balancing of two different criteria. Computational results for realistic scenarios are also discussed. References [1] A. Otto et al. Optimization approaches for civil applications of unmanned aerial vehicles (uavs) or aerial drones: A survey, Networks 72 (4) (2018) 411-458; [2] Amorosi L. et al., Energy-efficient mission planning of UAVs for 5G coverage in rural zones, IEEE International Conference on Environmental Engineering, EE 2018; [3] Chiaraviglio L. et al. Optimal Design of 5G Networks in Rural Zones with UAVs, Optical Rings, Solar Panels and Batteries, ICTON2018.

3 - Portfolio optimization with two levels of decision-makers
Marina Leal Palazón, Diego Ponce, Justo Puerto

Among the classical research problems in Operations Research and Financial Theory, we find portfolio optimization problems. Over time, these portfolio optimization problems have become more realistic, incorporating real-life aspects, such as transaction costs. The transaction costs are the costs incurred by the investors when buying and selling assets in the markets. They are charged by the brokers or the financial institutions playing the role of intermediary. Classically, these transaction costs are assumed to be fixed or variable, but given. Nevertheless, these intermediaries may also fix the transaction costs trying to maximize its own profit, that is, they can also be considered optimizers in the problem, and hence the transaction costs can become decision variables. We present novel bilevel leader-follower portfolio selection models in which the bank has to decide on the transaction costs, maximizing its benefits, and the investor has to choose his portfolio, minimizing the risk and ensuring a given expected profit. In order to minimize the risk of the investor different risk measures can be considered. This gives rise to general non-linear bilevel problems at both levels. We model different bilevel versions of the problem (social welfare model, bank-leader model, etc.), determine some of their properties, provide formulations and algorithms and report some computational results based on real-life financial markets.

■ MD-17

Monday, 14:30-16:00 - A005

Mobilizing distributed demand-side flexibility through advanced analytics

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: *Anthony Papavasiliou*
Chair: *Yuting Mou*

1 - A strategic modelling framework for investigating the role of demand-side flexibility in electricity markets
Roberto Moreira, Dimitrios Papadaskalopoulos

The envisaged decarbonization of electricity systems has attracted significant interest around the value of demand-side flexibility. However, this value has been analyzed in the existing literature through centralized models, optimizing system objectives and assuming perfectly competitive behavior by market participants. The recent deregulation of the electricity industry means that such models are not able to provide accurate and meaningful insights since they neglect that self-interested market players' actions are not generally aligned with social welfare optimization. This presentation demonstrates a new strategic modeling framework which is capable of capturing both the profit-driven behavior of self-interested market players and the complex time-coupling characteristics of demand-side flexibility. This framework is applied to investigate two key aspects around the role of demand-side flexibility in electricity markets, namely: 1) Its impact on the market power exercised by other self-interested market players, including large generation companies in wholesale markets and large electricity retailers in retail markets. This issue is explored through a multi-period bi-level optimisation approach. 2) Its own ability to exercise market power, considering the potential of overselling its flexibility in balancing markets while managing the risk of service non-delivery. This issue is explored through a robust optimisation approach, based on the min-max regret criterion.

2 - Day-ahead Operation of an Aggregator of Electric Vehicles via Optimization under Uncertainty
Alvaro Porras Cabrera, Ricardo Fernandez-Blanco, Salvador Pineda Morente, Juan Miguel Morales

Transport industry is undergoing a transition from fuel-based vehicles to electric vehicles, thus affecting the way electricity systems should be operated and planned in the short-term. Moreover, new actors such as aggregators come into play in this new paradigm of electrification of transport in order to manage the charging/discharging of electric vehicles. This paper assumes an aggregator of Electric Vehicles (EVs) with an energy storage battery.

The aggregator aims to sell and buy energy in the day-ahead electricity market while accounting for the technical aspects of each individual EV, which can be operated either on vehicle-to-grid mode or grid-to-vehicle mode, and the feeder capacity. We also model uncertainty: (i) on electricity prices by using historical scenarios, and (ii) on driving patterns via robust optimization. Thus, the aggregator's decision is driven by the minimization of the total costs including operation and degradation costs of the fleet of EVs. Finally, we use synthetic data from the National Household Travel Survey 2017 to analyze the behavior of the aggregator of EVs from both economic and technical viewpoints and compare it with the results from a deterministic approach.

3 - Optimal Grid - Distributed Energy Resource Coordination: Planning and Operational Planning Implications of the Short-Run Dynamic Locational Marginal Costs
Panagiotis Andrianesis, Michael C. Caramanis

With Distributed Energy Resources (DERs) emerging as a major user of the distribution grid infrastructure, the grid is becoming increasingly active, distributed, dynamic, and challenging to plan and operate. In addition, recent acceleration of DERs has raised the opportunity for considering them as Non-Wires Alternatives that enable deferral or avoidance of costly network investments to deal with anticipated load growth. As such, the value of DERs over time and location is the key driver of the optimal grid-DER coordination that is expected to bring about fundamental changes in distribution planning, operations and markets. We provide a tractable formulation of the operational planning problem, capturing salient features and costs of distribution assets, as well as the complex DER preferences and capabilities, which enables the discovery of short-run dynamic locational marginal costs. We present results from actual distribution feeders that indicate significant economic efficiencies in the presence of high DER (solar PV, electric vehicles, and the like) adoption. We also explore how short-run marginal cost based prices can be employed to mitigate capacity shortfalls and defer/offset network investments, thus disrupting the traditional network planning process.

4 - A Comparison of Priority Service versus Real-Time Pricing for Enabling Residential Demand Response
Céline Gerard, Anthony Papavasiliou

The unprecedented growth of renewable energy has led to various challenges in power system operations. Demand response can provide further flexibility to the system in order to balance the effects of the massive integration of renewable resources. This work focuses on the application of demand response to individual households and inferring the impact that results from its application on consumers' perceived quality of service. The analysis is centered on the impact to consumers by assessing the effects of these demand response schemes on their comfort and bill. The application is realized by means of a home energy management system algorithm that schedules appliances within the house by minimizing the discomfort experienced by the consumer. The algorithm is based on reinforcement learning techniques that allow scheduling appliances online after a training period, while still accounting for changes in consumers' behavior. The home energy router is used in order to compare two demand response schemes: real-time pricing and priority service pricing. We illustrate the concept using a simple example of a household with one appliance. It provides an end-to-end illustration of (i) how to design a priority service menu from a time series of real-time prices, (ii) how a household selects options from this menu, (iii) how devices are dispatched in the household by a home energy router, and (iv) what consumer welfare losses are relative to the golden standard of real-time pricing.

■ MD-18

Monday, 14:30-16:00 - C112

Deep Learning Theories and Applications I

Stream: Multiple Classifier Systems and Their Applications
Invited session
Chair: *Sureyya Ozogur-Akyuz*

1 - Classification by using CNN for EEG based measurements to Asses Creativity
Muhammad Ammar Ali, Busra Eksi, Mohammad Shkok, Farouk Sallak, Sureyya Ozogur-Akyuz, Adil Deniz Duru, Alper Almelek

In this study, the change of creativity ability in brain is analyzed before and after "creativity training" by using Event Related Potentials (ERP) of brain by EEG (Electroencephalography) signals. The second task is searching a correlation between change in brain EEG and one of the well known creativity questionnaire called "Kaufmann Creativity Test". The final goal of this study is to predict/update the score of Kaufmann test by using machine learning methods with the EEG data collected from participants of this experimental study and see whether the final score of the questionnaire performed by the participant after training needs to be updated by the machine learning algorithm developed for this research .The requirement of such update and prediction is needed since the questionnaire is answered by participants which is clearly a subjective task. The result of this study produces a quantitative reasoning for the increase of creativity after creativity exercises and then the correlation between the EEG results and Kaufmann creativity test is obtained.

2 - Stock Market Prediction Using Deep Learning Techniques
Rekha Ks, Sabu Mk

Stock markets are fluctuating and dynamic and the factors that influence stock prices are quite complex. In this paper an attempt is made to illustrate the power of Recurrent Neural Networks (RNN), Long Short Term Memory (LSTM) and Gated Recurrent Unit (GRU) in predicting stock price. Open High Low Close (OHLC) value of data for the stock of a reputed stock trading on National Stock Exchange (NSE) is taken for the experiment.The objective of the optimizers is to minimize or maximize the network's cost function and the computations that invoke the calculation of gradients that indicate the path in which the biases and weights have to be changed during training. In this paper we have used a default optimizer called Adaptive Moment Estimation (Adam) which is a combination of RMSprop and Stochastic Gradient Descent with Momentum. After analysing the results it is found that the predicted value lies very close to the target value for almost all the models and more accurately for Gated Recurrent Unit. The prediction accuracy of the model can be tested using methods such as Root Mean Square Error (RMSE) which is square root of average of squared errors.

3 - Burger Sales Forecasting in Quick Service Restaurants Using Wide-Deep Learning Neural Network
Alper Oner, Asmin Alev Aktas, Idris Atakli

In fast-food industry, traditional methods fail to improve operational efficiency. Evidently, a burger sales estimation system improves service efficiency and quality in many ways. With a precise forecasting, the amount of waste production decreases as the customer waiting time for ordering is not adversely affected.

According to our analysis of sales data, which we collected from different restaurants, pen and paper based sales predictions done by the restaurant managers deviate about 35-40%. This approach either produces extra food waste or extra long waiting times for customers.

In this paper, we have developed an innovative burger sales forecasting method for fast-food restaurants to better estimate the number of products to-be sold. By doing so, we aim to help employers save time and capital through cutting down on waste production, creating more precise employee-shifts depending on our sales forecast numbers, and optimizing customer waiting time.

We employed a wide & deep neural network method to lower down the error rate to about 15%. Wide & deep neural networks helped us better handle weak and sparse features dynamically. We trained our model with 2-year long sales data collected from different fast food restaurants. Furthermore, we compared our results to deep neural network methods and proved the efficiency of our algorithm in real world fast-food environment.

4 - A Deep Learning Approach to Sentiment Analysis
Tiny Du Toit, Nicolaas Maree, Lynette Drevin, Hennie Kruger

Response bias may lead to inaccuracies and invalid results when participants do not provide honest information in questionnaires and surveys. Participants' true opinions may be identified by analysing their facial expressions and modelling sentiment using techniques from the field of affective computing. The aim of this study is to determine whether a deep neural network can be used together with affective computing to model sentiment in order to address response bias. Training data were obtained by making video recordings of the participants' faces and then extracting affective data while they completed a questionnaire. This data were then used to construct a deep neural network in order to model sentiment. Very high sentiment accuracies were obtained with the deep neural network which indicates that this technique is feasible.

■ MD-19

Monday, 14:30-16:00 - C115

Knowledge Analytics Applications II

Stream: Knowledge and Knowledge Analytics
Invited session
Chair: *A. D. Amar*

1 - Multi-criteria decision model for assessing risk of ventilator-associated pneumonia
Vladislav Rajkovič, Rok Drnovšek, Tanja Rupar, Marija Milavec Kapun

Ventilator-associated pneumonia is one of the most common infections in intensive care hospital settings. It causes a high mortality rate and is related to high financial costs of treatment. We have developed a multi-criteria decision model for assessing the risk of acquiring ventilator-associated pneumonia. The model is based on an expert system shell DEXi. It contributes to the understanding of the risks and preventive measures. It was tested by a nursing team in practice and shows great potential for use of similar models in health care in practice as well as in education.

2 - Analysis of the regional convergence across the EU: different spatial perspectives
Michaela Chocholatá, Andrea Furková

The elimination of regional disparities among the EU regions has been a challenging issue for some years. The concepts of beta-convergence and sigma-convergence can be viewed as traditional instruments for testing and analysing of the regional convergence. This paper presents the augmentation of the traditional beta-convergence approach considering the spatial dimension in the analysis of the income convergence of the EU regions. Both spatial effects - the spatial autocorrelation and spatial heterogeneity are considered. Besides the traditional non-spatial ordinary least squares (OLS) approach, the global spatial econometric analysis based on spatial autoregressive (SAR)/spatial error models (SEM) is applied. The local spatial econometric approach enabling to capture the spatial heterogeneity across analysed regions, i.e. different speed of convergence for every region, the geographically weighted regression (GWR), is presented as well. Based on the global spatial econometric models the beta-convergence concept was confirmed. The results furthermore showed that the local GWR approach describes the data set significantly better than the global OLS model. Simultaneous modelling of both the spatial autocorrelation and spatial heterogeneity in convergence analysis based on a geographically weighted version of spatial regression model could be the subject of the authors' future studies.

3 - Multiplier Analysis: Identifying the Most Influential Sectors of the Slovak Economy
Veronika Mitkova

The production side and the connections among the sectors of the economy was studied in this research. In the first part, the Social Accounting Matrix (SAM), based on the Global Trade Analysis Project data, was created for 57 sectors of the Slovak economy. Besides that, the matrix contains one representative household, regional government, two production sectors: labor and capital and the rest of the world accounts. The taxes are included to the commodities and production factors accounts. This detailed view of the economy allows us to construct not only the input-output coefficients but more complex constrained and unconstrained multipliers for each production sector. The multiplier analysis, based on the classic Leontief model, identifies the backward and forward economic linkages among the individual sectors and points out the most influential sectors of the Slovak economy. The constrained multiplier considers the limitations in the supply side of economics to the external demand shocks, thus allows more representational analysis of flows and relationships. The research answers the question, i.e. which sector of the Slovak economy might be supported by government stimulus and what is the total effect of such exogenous demand increase to all sectors and households in the Slovak economy.

■ MD-20

Monday, 14:30-16:00 - C006

Business Analytics and Machine Learning

Stream: Business Analytics
Invited session
Chair: Sebastian Maldonado

1 - Profit Maximization for Churn Prediction via Robust Optimization and Learning Machines
Sebastian Maldonado, Julio López

Churn prediction is a well-known business analytics task whose goal is to identify customers that are likely to leave a company voluntarily. Once potential churners are detected, a retention campaign is performed for enhancing customer loyalty. This is extremely beneficial for customers since engaged customers generate more revenue than other clients, it reduces operational costs, and it avoids the misspending of money caused by inefficient marketing campaigns. In this study, a novel profit-driven method is presented for churn prediction. The Minimax Probability Machine (MPM) method is extended to business analytics. Unlike most profit-based approaches that use profit metrics for choosing between classification techniques and/or to define the optimal classification threshold, our proposal maximizes the profit of a retention campaign directly in the objective function using a robust optimization setting. Experiments on well-known churn prediction datasets demonstrate that our proposal leads to the largest profit in comparison with other binary classification methods.

2 - Optimal Title-Body Combination for NLP Analysis of Reviews via SVM Classification and Genetic Algorithms
Carla Vairetti, Sebastian Maldonado, Francisco Herrera, Eugenio Martínez Cámara, M. Victoria Luzón

Sentiment analysis is a new challenging task related to Text Mining and Natural Language Processing (NLP). It aims to determine the attitude of people with respect to some topic. Although there is a vast literature on this topic, most studies focus on English texts. Limited research has been conducted applying social media analysis in hospitality research. One of the most important fields where Sentiment Analysis has a greater impact is in the industrial field. Spanish is increasingly present so we have carried out an experimental study with three Spanish corpora: two corpora of reviews detailing travelers' experiences with restaurants and hotels (TripAdvisor and COAH), and a corpus of movie reviews (MuchoCine). Our main goal is to develop an optimal title-body combination using Support Vector Machines (SVMs) and genetic algorithms. In fact, our hypothesis is that a word that appears in the title of the comment is more important than one in the body, and the usual title-body aggregation leads to loss of information. We compared our proposal with different strategies using the l1-SVM model. The proposed method was compared with three alternative techniques for two representations, three n-gram strategies, and 14 pre-processing approaches. For each of the three corpora and the six representation/n-gram combinations, the best pre-processing strategy is reported. The accomplished experiments show that our proposal outperformed the other methods in all the experiments.

3 - Deep Learning for Micro and SME Credit Scoring
Matthew Stevenson

Personal credit risk models are built upon a wealth of structured sociodemographic and behavioural data. It tends to be high in volume and low in cost, and as a result, personal lending is a highly automated process. This, however, is not true for Micro and Small businesses credit processing which is cumbersome and expensive for lenders. Often, a lack of sufficient structured data and the bespoke nature a credit request requires expert judgement on the creditworthiness of an organisation. This occurs in the first instance by a financial analyst who generates a written report, which is then usually passed onto a further assessor who makes the final decision based on the written report combined with other sources of available data.

In recent times there has been a rapid development of Deep Learning techniques capable of extracting information from unstructured sources of data such as images, sound and text. In our presentation, we explore the application of Deep Learning techniques applied to textual loan assessment statements for the prediction of over 60,000 Micro and SME loans.

Our initial results suggest that while textual data does hold predictive power, only in particular cases is additional performance gained when textual data is combined with traditional credit scoring data. We consider the features of the applicants and textual statements to identify where Deep Learning can enhance credit risk prediction.

■ MD-21

Monday, 14:30-16:00 - F101

Lot Sizing IV - Stochastic and robust lot-sizing

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: Kerem Akartunali

1 - A Min-Max Approach for the Robust Two-level Multi-Component Lot Sizing Problem with Remanufacturing
Oyku Naz Attila, Agostinho Agra, Kerem Akartunali, Ashwin Arulselvan

In this paper, we study the robust two-level lot sizing problem with the option of remanufacturing. We consider a single item on the upper level under deterministic independent demand, and multiple components on the lower level under dependent demands. Our problem consists of the decisions related to manufacturing and remanufacturing (to satisfy lower level demand), assembly of components (to satisfy upper level demand), as well as inventory decisions for components, the final item, and returned items. The robustness on this problem stems from the uncertainty on the number of items returned, which are defined as parts of uncertainty sets. To solve this problem, we propose a decomposition approach consisting of two subproblems: the Decision Maker's Problem (DMP) and the Adversarial Problem (AP). This approach mainly consists of an iterative procedure between the two subproblems, where the optimal solution to DMP minimizes total costs over a subset of return scenarios obtained from AP. These scenarios are sought within the uncertainty sets, such that in each iteration the total cost for the current production plan is worsened.

2 - Lot Sizing for a Perishable Item
Hande Yaman, Nazlican Arslan

Motivated by the inventory management for blood products, we address the uncapacitated lot sizing problem for a perishable item that has a deterministic and fixed life time. In the first part of the study, we assume that demand is deterministic and conduct a polyhedral analysis. In the second part, we study a multistage stochastic version of the problem where demand is uncertain. As the size of the model grows exponentially in the number of periods, we implement a scenario-wise decomposition method to obtain lower and upper bounds. In order to improve the quality of lower bounds, we use a subgradient algorithm.

3 - Lot Sizing with Stochastic Demand Timing
Kerem Akartunali, Stéphane Dauzere-Peres

The stochastic lot sizing literature is almost exclusively concerned with uncertainties regarding 'quantities', in particular levels of demands, and uncertainties in other key aspects such as cost parameters or lead times are investigated rather rarely. A case of interest that often stems from practice is when demand quantities are deterministic while their timings are uncertain. To the best of our knowledge, such a case has not been studied in the literature before. In this talk, we present a novel way to model this problem, and discuss a number of its key properties. For the simplest case with a single item, we investigate general and special cases of the lot sizing problem with stochastic demand timing, and propose dynamic programming approaches. To conclude the talk, we discuss future research including extensions to more challenging settings.

■ MD-22

Monday, 14:30-16:00 - F102

Production planning and scheduling in low-volume manufacturing

Stream: Production Planning and Control for Complex Manufacturing Systems
Invited session
Chair: Alexander Biele
Chair: *Lars Moench*

1 - Production Planning and Scheduling in airframe manufacturing: a case study
Tamara Borreguero Sanchidrián, Raul Pulido, Miguel Ortega-Mier, Álvaro García-Sánchez

Industry 4.0 means a deep transformation for the total enterprise where smart factories constitute a key feature. To do so, they integrate physical objects with information systems such as MES and ERP. However, on many industries scheduling and line balancing have consistently remained unaffected. Most of the activities related to these processes continue to use manual procedures that rely on the knowledge of experts. Nevertheless, scheduling problems have been for long studied within Operations Research. However, that low integration level is caused by the lack of standard tools that cope with this problem. That is the case also in aircraft manufacturing, where special features due to its low volume production are barely addressed in commercial solutions. In this study, we have analyzed the production planning and scheduling process for an airframe manufacturer. This analysis has been from an end-to-end approach. It compromises the yearly aggregate production planning, the detailed scheduling and also the incidence management in two approaches: a preventive one (to assess the robustness) and a corrective one. We have used mixed integer linear programming for yearly planning and production planning together with discrete event simulation for robustness assessment. As a result of this holistic approach, solutions from one step are a valuable feedback for the others. Moreover, solutions have been tested against real data an validated in terms of quality and solution time.

2 - Reoptimization approach to deal with disruptions in low-volume assembly lines
Olga Battaïa, Lorenzo Sanmartin, Cedric Pralet

Unexpected events can compromise the execution of the production schedule in low-volume assembly lines. When a disruption occurs because of a delayed part supply, a quality problem or an operator absence, a reactive scheduling approach should be used in a short time in order to prevent significant deviations in final performances. In this study, we propose a new approach based on constraint programming. It is tested on a large dataset of problem instances and the obtained results are discussed.

3 - Simulation Aided Production Planning and Control for Complex One-of-a-kind Products
Dirk Steinhauer

Production planning for complex one-of-a-kind products faces various challenges: since the product and its complexity determines main parts of the production process, different products or even variants require a different production planning. The high number of variants within the complex product causes changing workloads throughout the production flow and in the production facilities. Bottlenecks are changing not even between different products but also within one construction project. Hence, fixed production strategies can rarely be successfully implemented. The challenge in one-of-a-kind production planning and control is to manage the production flexibily in the context of the specific production programme considering the actual production progress.

Discrete event simulation has been proven as a powerful tool to support the production planning and control in analysing the current or upcoming situation considering the dynamic dependencies between the product, the production process and the resources.

In order to use simulation in production planning and control, the simulation model is integrated into the data infrastructure of the company.

Examples from shipbuilding or construction industry show the benefits of simulation aided production planning and control: • Capabilities to analyse the current or upcoming situation • Cost-efficient trials for various planning scenarios • Significant increase in planning reliability • Model based decision making

4 - Car-Sequencing Rules for Assignment and Sequencing Decisions in Aircraft Manufacturing Flow Lines
Alexander Biele, Lars Moench

A manufacturing system consisting of two subsystems is considered in aircraft manufacturing. Parallel mixed-model assembly lines form the first subsystem while the second subsystem consists of parallel stations. The subsystems are decoupled by a finite buffer. A combined objective function is used that accounts for total weighted tardiness (TWT) and makespan. The jobs must be assigned to one of the parallel assembly lines. They then have to be sequenced at each single assembly line. Assignment and sequencing decisions have to be made for the jobs at the remaining subsystem to compute the objective function value. A biased random-key genetic algorithm is used to determine a sequence of the jobs. List scheduling with car-sequencing rules is then applied to this sequence to assign jobs to the assembly lines and to sequence them. These rules determine, for instance, a minimal distance between two models or restrict the assignment of a model to a specific flow line. List scheduling is again used for the second subsystem. Outsourcing is required to take into account the finite buffer. Results of computational experiments based on randomly generated problem instances demonstrate that the proposed decomposition scheme performs well.

■ MD-23

Monday, 14:30-16:00 - F103

Assortment Planning and Pricing

Stream: Demand and Supply Management in Retail and Consumer Goods
Invited session
Chair: Rob Broekmeulen

1 - Optimizing Revenue over Data-driven Assortments
Theja Tulabandhula, Deeksha Sinha

We revisit the problem of large-scale assortment optimization under the multinomial logit choice model without any assumptions on the structure of the feasible assortments. Scalable real-time assortment optimization has become essential in e-commerce operations due to the need for personalization and the availability of a large variety of items. While this can be done when there are simplistic assortment choices to be made, not imposing any constraints on the collection of feasible assortments gives more flexibility to incorporate insights of store-managers and historically well-performing assortments. We design fast and flexible algorithms based on variations of binary search that find the revenue of the (approximately) optimal assortment. We speed up the comparisons steps using novel vector space embeddings, based on advances in the information retrieval literature. For an arbitrary collection of assortments, our algorithms can find a solution in time that is sub-linear in the number of assortments and for the simpler case of cardinality constraints - linear in the number of items (existing methods are quadratic or worse). Empirical validations using the Billion Prices dataset and several retail transaction datasets show that our algorithms are competitive even when the number of items is ~105 (100x larger instances than previously studied).

2 - Postponed two-pricing and ordering opportunity for selling a single season inventoried product
Matan Shnaiderman

Postponement strategies are becoming increasingly important in light of a global trend in which products' life-cycles are decreasing, such that even products that are not traditionally considered seasonal become "obsolete" within a short period of time. Our work addresses postponed-pricing and ordering decisions for a retailer who sells a newsvendor-type inventoried product, in a selling season that is divided into two sub-periods. The division of the selling season enables the retailer to on-line adjust her decisions when faced with a scenario in which potential demand changes following consumers' experiences of the product in early stages of the selling season. We assume that the retailer has two opportunities for receiving shipments: prior to the first sub-period and prior to the second one. The retailer determines each order quantity on the basis of the demand distribution for the corresponding sub-period. In each sub-period, after observing additional market signals, the retailer determines the price of the product for that sub-period. We develop optimization problems and solution methods in order to obtain pricing and ordering decisions that maximize the expected profit of the retailer. We present an extensive numerical example that compares the suggested strategy to three alternative strategies, and conclude that price postponement and responsiveness to demand changes can each reduce leftovers and lost sales as well as substantially increase expected profit.

3 - Category Pricing Optimization Using Data Driven Constraints
Luis Aburto, Marcel Goic

Multiproduct pricing is an important decision in retail management but present several challenges. To capture cross-elasticities, demand systems tend to be highly parameterized and potential endogeneity of prices might lead to parameters with signs different than expected. Additionally, when solving for optimal prices, first order conditions frequently suggest extreme solutions which are beyond of what managers consider reasonable. In this research we analyze transactional data to identify what business rules have been consistently applied before and evaluate which ones are associated to better business performance. Based on these pricing rules, we build a data-driven set of feasible prices and combine it with standard price optimization routines to understand how this information can complement traditional econometric analysis of the demand. This novel approach for pricing optimization is easy to implement and not only provide mangers with a reliable automatic mechanism to decide about prices of multiple products, but also more consistent decisions.

■ MD-24

Monday, 14:30-16:00 - F103A

Global Supply Chains

Stream: Supply Chain Management
Invited session
Chair: *Isilay Talay*

1 - Global Supply Chain Design under Fluctuating Antidumping Tax Rates for Export
Orkun Bayram, Isilay Talay

Profit from exports for a country could be substantially affected in case of a sudden increase in the antidumping tax rates of a major importing country. There have been recent fluctuations in antidumping taxes applied by countries such as US for important industries, e. g. steel production. A natural reaction of exporting countries to such unanticipated changes is to search the possibilities of new markets to export. However, extending the supply chain into new markets requires prior set up for activities such as marketing and transportation. Thus, companies subject to antidumping tax rate fluctuations for export require a decision framework for investing to create new markets to hedge for the unplanned decreases in the demand and revenues caused by increased antidumping taxes at their importing countries. In this study we present a stochastic optimization model to decide on investment for a new market and production decisions for profit maximization to hedge for sudden antidumping taxes imposed under production and transportation quantity constraints. We demonstrate the decision policies based on the values of different parameters such as the probability of increase in the antidumping tax rates, demand distributions and monetary parameters.

2 - Optimal Payment Scheme Selection in Global Supply Chains
Isilay Talay, Orkun Bayram

Cross-border payments are one of the main terms in an international trade contract, and blockchain technology started to challenge the traditional intermediary channels for making such payments, e. g. the SWIFT network. The paper considers the selection of cross-border payment scheme, where the seller is considering whether it would be more beneficial for him/her to use blockchain technology or SWIFT to complete the transaction. The seller's profit function, which includes late transaction fees, exchange rate/cryptocurrency fluctuations during the payment interval, and the compensation in case of an incomplete transaction, is analyzed for both payment schemes with the selling price and the type of payment scheme being the decisions made by the seller. For different parameter sets of sales quantity, late transaction fees, transaction costs, and incomplete transaction compensation, as well as different exchange rate/cryptocurrency fluctuation distributions, optimal decisions are demonstrated to provide insights to sellers on which payment scheme to favour in different currency exchanges and other contract terms.

3 - A Large-Scale, Real World Supplier Selection Problem for a Multinational Company
Michele Garraffa, Yiqing Lin, Steve Prestwich, Helmut Simonis, Federico Toffano, Nic Wilson

One of the most common ways to improve supply chain operations is changing the strategy for selecting the suppliers. Given a set of components with a certain predicted demand and a set of suppliers, each offering a subset of the components, the problem consists of determining the quantities of components to be ordered from each supplier. Many objectives (cost, quality, reliability, etc) and constraints (min/max number of suppliers, component availability, etc) have been considered in the literature, leading to very different problem definitions and solution approaches.

We tackle a real world supplier selection problem arising in a multinational company in the field of stationary equipment in buildings. In this context, the decision making process involves a few thousand components/suppliers, evaluated according to multiple objectives. First, we provide an automated approach to rank the suppliers according to the objectives, based on the use of historical data and expert opinion. Second, we formulate the problem as a multi-objective combinatorial optimization problem and provide heuristic solution methods. Our approach will be tested by considering realistic instances constructed by extracting information from publicly available supplier and company spend data. We will present the structure of the approach, as well as the mechanisms to reproduce realistic instances and some computational results.

4 - Implications of three-dimensional printing (3DP) on the humanitarian supply chain
Nicola Rupp, Christian Wankmüller

Logistics is key in a disaster affected area as a lot of goods are missing. Still there is often a substantial gap between supply and demand. In general only standardized goods are delivered by disaster relief organizations. Especially the transportation of spare parts or highly individualized relief items is time consuming and of relatively high costs. Here additive manufacturing techniques such as three dimensional printing (3DP) offer on-demand production of individualized products, which can even be designed on scene. Therefor 3DP has the potential to supplement the humanitarian logistics framework. After a short presentation of the state of the art based on a systematic literature review, this paper presents a possible extension of the humanitarian supply chain process model by Blecken (2010). While Bleckens reference model framework consists only of the phases Needs Assessment, Procurement, Warehousing and Transport, this paper will outline that 3DP can add Production as an additional phase. Here the integration into the operational, tactical and strategic level will be analysed. Hence 3DP seems to allow for an enlargement of the scenarios for the reference process by the production of non-standard items during emergencies. The implication on the needs assessment as well as the entire configuration of the humanitarian supply chain itself are evaluated. Finally, results are validated by means of an expert interview.

■ MD-25

Monday, 14:30-16:00 - F104

Quantitative Decision Support Methodologies for Supply Chain Planning and Control I

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: *Pablo A. Miranda*
Chair: *Francisco J. Tapia-Ubeda*
Chair: *Oscar Romero-Ayala*

1 - The bullwhip effect in hybrid systems with manufacturing and remanufacturing capacity constraints
Salvatore Cannella, Roberto Dominguez, Borja Ponte, Jose M Framinan

In this work we study the dynamics of a Closed-loop Supply Chain (CLSC) via difference equation modelling, characterized by a limitation in both manufacturing and remanufacturing operations. We perform a Design of Experiment considering four key factors, i.e., (1) the variability of the return yields, (2) the capacity factor of the manufacturer, (3) the capacity factor of the remanufacturer, and (4) the variability of the customer demand. Results reveal that a low capacity in the remanufacturer may smooth the BWE in the fabrication of both new and remanufactured products while maintaining a good inventory performance. However, if capacity is reduced below certain threshold value, it can also generate detrimental consequences in terms of inventory holding costs and customer service level. From a managerial point of view, this work suggests that imposing capacity limits in both remanufacturing and manufacturing processes can be adopted as a bullwhip-dampening method. In order to the set suitable capacity of both nodes, managers should also take into account degree of uncertainty of both the market demand and the return yield.

2 - Outbound supply chain optimization by a combined approach of reinforcement learning and mathematical programming
Munjeong Kang, Yukyung Lee, Jinyoung Cho, Chungmok Lee

We present a novel optimization framework for an outbound supply chain optimization problem by combining the classical optimization approaches and reinforcement learning (RL). The supply chain network under consideration in this talk consists of three entities: plants, distribution centers (DCs), and dealers. The decision process includes the capacities of DCs, daily batch transportation between DCs, and delivery vehicle routing for the dealers. Recently, the RL has been successfully applied to various applications including games like Go (e.g., AlphaGo by Google). We incorporate the RL into the supply chain optimization which results in a three-stage optimization framework: (1) network design via mixed integer programming, (2) intra-DC transportation via the RL, and (3) final delivery via vehicle routing heuristics. The results show that the proposed approach can reduce the operation cost considerably for the real-world use case.

3 - A quantitative methodology for supply chain measurement and enhancement
Dylan Jones, Graham Wall, Natawat Jatuphatwarodom

This seminar presents a quantitative methodology comprising three Operational Research techniques in order to provide decision support to stakeholders in Thai silk supply chains. Firstly, Data Envelopment Analysis (DEA) is used in order to assess the efficiency of current suppliers and processes. Secondly, the Analytical Hierarchy Process (AHP) is used to elicit the relative importance of a set of criteria for the improvement of the supply chain efficiency to silk manufacturers. Thirdly, extended goal programming (EGP) is used to select a set of proposed actions for the improvement of supply chain efficiency from among a set of potential improvement actions. The advantages and drawbacks of combining the three techniques are discussed from the perspective of a holistic framework. Case studies involving two supply chain improvement situations and a set of Thai silk manufacturers and suppliers are given and the results are discussed.

4 - Managing the reverse flows of a divergent closed-loop supply chain: centralization vs decentralization
Roberto Dominguez, Salvatore Cannella, Jose M Framinan

A strategic driver of the Circular Economy is irrefutably the Closed-Loop Supply Chain (CLSC), a logistic structure that simultaneously considers forward and reverse operations. Managing the reverse flow adds new sources of uncertainty to the supply chain, and the bullwhip effect shows up. Most of the related studies assume serial CLSCs with a single reverse flow. In this study we model a more complex CLSC structure, emulating a divergent/distribution CLSC, where there are several end-customers and several reverse flows. Through a simulation study, we analyse two different settings: (1) a centralized setting, where all the reverse flows are managed by a single remanufacturing entity, and (2) a decentralized setting, where each reverse flow is managed by an independent remanufacturing entity. We found that by centralized the remanufacturing operations, the supply chain nodes receiving the remanufactured products are highly benefitted, showing reduced order and inventory variabilities. This benefit can be comparable to that obtained by implementing an information transparency scheme. However, this centralization may increase the correlation of the reverse flows, which in turn, amplifies the order and inventory variability to the upstream nodes of the CLSC. A win-win strategy for the entire CLSC can be achieved by combining a centralized setting with an information transparency scheme.

■ MD-26

Monday, 14:30-16:00 - F106

Service Operations II

Stream: Service Operations Management
Invited session
Chair: Melike Yıldız

1 - On the added value of advance demand information for the multiple job repair kit problem
Christoph Rippe, Gudrun Kiesmuller

The multiple-job repair kit problem is related to the question of a repairman who has to decide which spare parts he has to put in his repair kit when he visits several customers in a tour. Within this repair tour the service technician is unable to restock his kit. Contrary to previous studies we assume these customers provide the customer service support center with information about their malfunctioning appliances' conditions, such as error codes, upon requesting a repair job. Thus, the repairman is able to obtain some information about the spare parts required by the customers in advance of his first visit. We assume this advance demand information is available only for some parts that can either be monitored by a sensor or examined by the customer himself. In case it is available we expect the advance information to be perfectly reliable. The inventory of all parts in the repair kit is managed according to individual (s,S)-policies, but the inventory positions are defined differently for parts with and without advance demand information. We derive a formula for the job fill rate and show how to minimize the total sum of inventory holding and material handling costs subject to a service level constraint. In a numerical study we demonstrate that making use of advance demand information yields significant savings. Further, we identify the part characteristics leading to the largest cost savings if equipped with technology to get more information.

2 - Carpool Services for Ride-sharing Platforms
Xuan Wang, Renyu Zhang

There has been rapid growth in on-demand ride-hailing platforms that serve as an intermediary to match individual service providers with consumer demand. We study the carpool services of a ride-sharing platform. The carpool services allow passengers heading towards the same direction to share a ride at a discounted fare. We study the operational issues faced by a ride-sharing platform in the presence of carpool services. We show that carpool services enable the platform to achieve a larger market coverage and lower prices. Using the operational data from San Francisco, we find that carpool services could also reduce the price variability riders face. As two operational leverages to match supply and demand, carpool services and surge pricing are complements when demand-supply ratio is large or small, but are substitutes when demand-supply ratio is moderate.

3 - Self-controlling electric vehicle charging stations using feedback control
Melike Yıldız, Nilgun Fescioglu-Unver

This study presents a dynamic resource allocation model based on closed loop control, for electric vehicle charging stations that provide express service to a designated class of users. Express service logic divides the charging stations' customers into two classes - express and normal class - based on their service time requirements or predetermined priorities. The feedback control model presented in this study is based on control theory and provides a relative delay guarantee to the user classes. The electric vehicle charging station is handled the system to be controlled, where the control input is the charging unit-class allocations and the controlled output is the ratio of the delay times of the express and normal classes. The delay time ratio is monitored in real time and the model dynamically changes the allocation of the charging units to the classes such that the delay time ratio stays at a given reference level. We evaluate the performance of the model in a hybrid simulation environment and compare the model with existing express service models.

■ MD-27

Monday, 14:30-16:00 - F107

Financial Mathematics and OR 1

Stream: Financial Mathematics and OR
Invited session
Chair: Tadashi Uratani

1 - Insurance Linked Security: Cat Bond vs Collateralized reinsurance
Tadashi Uratani

Growing demand for Insurance Linked Securities, the share of collateralized reinsurance is more increasing than catastrophe bonds. We assume the Merton's jump diffusion as the insurance loss process and we formulate insurance premiums by Option formulas. We compare the premiums of Insurance for insurance company for using (1) catastrophe bond (2) collateralized reinsurance of the capital market and (3) using reinsurance of the reinsurance company.

2 - An Accelerated Static Hedging Method for Pricing American Options under J-Process
Lung-fu Chang, Jia-hau Guo, Mao-Wei Hung

This article provides an accelerated static hedging method for pricing American options based on the J-process, which is provided by Jerbi (2015). Jerbi proposes a generalization of the Black-Sholes model to capture the asymmetry and tail properties of the dynamics of the underlying asset, allowing it to fit the reality of financial markets with good accuracy. Our proposed model utilizes the static hedge portfolio method and the Repeated-Richardson extrapolation approach to evaluate American options under the J-process. The static hedging method of American options is established by utilizing the value-matching condition and smooth-pasting conditions on the early exercise boundary. The static hedge portfolio of an American option is established by using the value-matching and smooth-pasting conditions on the early exercise boundary. We use numerical examples to compare the values of American options from our proposed method with the benchmark values from the least-square Monte Carlo simulation method. Numerical results show that our proposed method is efficient and accuracy in pricing American options under the J-process.

3 - Multivariate dynamic models for management of currency investment portfolios
Tomas Cipra, Radek Hendrych

The contribution deals with dynamic models of conditional volatilities and covolatilities. The recursive estimation procedure for these models suggested in the contribution enables to apply them for financial data observed with a higher frequency when moreover strong conditional correlations are common. In particular, this approach is suitable for foreign currency exchange rates in the context of currency investment portfolios. One shows in the presented case study that predictions and various criteria based on corresponding models can be useful in investment practice.

4 - A new measure of multicollinearity and an application to financial systemic risk
Maria Laura Torrente, Mario Maggi, Pierpaolo Uberti

A new measure of multicollinearity is presented. The proposed measure exploits and extends the classical notion of condition number of a matrix, which is essentially based on the concept of singular value decomposition. In particular, it is shown that our collinearity measure has fundamental relations with both the numerical rank and the stability of the underlying data matrix. Based on the recent literature, the proposed measure can be effectively adopted in the realm of financial markets, where it can be successfully used as a supplementary indicator for financial systems risk analysis as well as a robust tool to forecast financial crisis. The proposed indicator is applied to different stock market indices and compared with alternative existing measures of systemic risk.

■ MD-29

Monday, 14:30-16:00 - C118

Metaheuristics Frameworks

Stream: Metaheuristics
Invited session
Chair: Caroline Gagne

1 - Solving the K-Traveling Repairmen Problem with a Quantum Particle Swarm Optimization
Sirine Jmal, Boukthir Haddar, Habib Chabchoub

We deal with an NP-hard combinatorial optimization problem encountered in the field of transport of goods and services, namely the K-Traveling Repairmen Problem (K-TRP). This problem is a generalization of the Traveling Repairman Problem (TRP) where more than one repairman is engaged. The K-TRP and the related problems can be considered as "customer-centric" routing problems because the objectif function consists in minimizing the sum of the waiting times of customers rather than the vehicles travel time. These problems are also considered as problems with "cumulative costs". We propose a Quantum Particle Swarm Optimization (QPSO) method to solve the K-TRP. Instead of the penalty function technique commonly used for constrained problems, we incorporated a K-TRP-specific repair operator within the proposed approach to ensure that the search process will always be guided through a feasible solution space and to improve the solutions' quality (if possible). This study is the first to report on the application of the QPSO method to the K-TRP. Experimental results obtained on a wide set of benchmark problems clearly demonstrate the competitiveness of the proposed method compared to the commercial MIP solver CPLEX 12.5 of IBM-ILOG and the state-of-the-art heuristic methods.

2 - A metaheuristic for the capacitated location routing problem based on grasp and on operators of diffuse logic
Maria Borja, Helman Enrique Hernandez Riaño, Jorge Mario López Pereira

The objective of the presented research was the creation of a new metaheuristic which seeks to emulate the decision making of human reasoning, in the solution of the problem of location and routing of vehicles with routes and capacitated depots (CLRP), which is made up of others two subproblems: location of depots and vehicle routing, both with NP-hard complexity. The proposed approach was carried out using heuristics used in the GRASP algorithm approach proposed by Ferdi and decision operators of Takagi-Sugeno based on four fuzzy logic rules. To evaluate the performance of the proposed algorithm, different instances found in the literature were used, obtaining good results in the solutions of the problem studied.

3 - A new multiobjectif migrating birds optimization algorithm for a permutation flowshop scheduling problem
Caroline Gagne, Aymen Sioud, Marc Gravel

Globalization requires companies to be more competitive. This quest for competitiveness requires them to optimize their production systems which, in some configurations, generate complex problems. One way to obtain approximate solutions is to use metaheuristics. Unfortunately, in the real world there are rarely simple problems and companies face often more complex situations requiring the resolution of several objectives. These problems where we seek to optimize several objectives are called multi-objective problems. We present here a new multiobjectif migrating birds optimization algorithm algorithm adaptation to solve a multi-objective permutation flowshop with sequence-dependent setup times. The migrating birds optimization (MBO), a nature-inspired metaheuristic for combinatorial optimization problems. The "V" formation seen in birds' migratory flying allows the birds to save energy and thus travel longer distances. The MBO reproduce this process and alternate intensification and diversification. For this problem, the makespan and the total tardiness are the two objectives studied. In order to identify the best solutions in the Pareto Front, the neighbor will be sort using the isolation factor and the isolation factor. Numerical experiments on various benchmarks from the literature were performed, to compare the performance of the adapted algorithm with the NSGA-II and GISMOO algorithms.

4 - A population-based Metaheuristic Approach for Solving the Multi-demand Multidimensional Knapsack Problem
Yun Lu, Francis Vasko

The Multi-Demand Multidimensional Knapsack Problem is a combinatorial optimization problem with real-world applications that is extremely difficult to solve due to conflicting constraints. In this study, we adapt a population-based metaheuristic, called Jaya, to efficiently generate near-optimal solutions to the Multi-Demand Multidimensional Knapsack Problem. In this talk, we will report empirical results we obtained from solving 810 MDMKP instances using our new Jaya-based metaheuristic approach.

■ MD-30

Monday, 14:30-16:00 - C007

Data Science in Optimization Algorithms

Stream: Data Science Meets Optimization
Invited session
Chair: Andrew J. Parkes

1 - Pre-processing and Anomaly Detection of Flight Data
Zhiyang Liu, Hyo-Sang Shin, Antonios Tsourdos

This paper compares several pre-processing techniques in the anomaly detection of flight data. The flight data come from NASA and contain 186 parameters. We have an option to treat one whole flight as a data point, treat the data of a flight at a particular time as a data point, or treat the flight data in a time interval as a data point. Since the sampling rates of the parameters are not the same, we have to unify the number of sampling points for each flight, and there are many ways to unify the number of sampling points. Since the data set is very large, it could take a long time to analyse if we use the original data. Aggregation is the summarization of data to show the main characteristics of the data, such as the mean, variance, maximum and minimum. We propose different ways to aggregate the data so that they become easier to analyse. However, we also need to retain as much anomalies as possible and avoid the disappearance of anomalies after aggregation. After pre-processing, clustering will be used to partition the data set into clusters where the data points in each cluster are close to each other, and the data points in different clusters are far away. The closeness can be measured using different distances such as Euclidean distance and Chebyshev distance. Isolated points will be regarded as anomalies. The performances of different pre-processing techniques will be compared through experiments and the results will be presented.

2 - Data Driven Models for Predictive Maintenance and Maintenance Scheduling
Kenan Cem Demirel, Erinc Albey

Predictive maintenance and maintenance scheduling ensure the most accurate estimation for the timing of breakdown and taking necessary precautions by analyzing the data provided from the equipment monitored in various periods. In this study, real-life sensor data is obtained from metal press machine department of a global electronics company. Metal press department in the facility consists of twenty-four metal machines of varying size and capacities. Collected data is transformed into a structure which enable us to develop statistical prediction models to estimate breakdown risk of the critical components over a predetermined time interval. Survival analysis is used as the main method to predict timing of breakdown events. Estimated breakdown times are then provided into a mixed integer programming model, which aims to schedule maintenance events of the critical parts by considering capacity and of maintenance team. If results are going to be promising, proposed system is going to be implemented as a decision support system with further investment from the company.

3 - Predicting Internal Fraud in Banking
Ekrem Duman

For building successful predictive models one should have enough number of examples for the class to be predicted (the positive class). When the number of examples of the positive class is very small, building strong predictive models becomes a very challenging task. In this study we pick up one such problem: predicting the bank personnel which might commit fraud (stealing money from customer accounts). For this problem, in order to have a strong enough predictive model, we decided to combine the powers of descriptive and predictive modeling techniques where we developed several descriptive models and used them as an input of a predictive model at the last stage. The results show that our solution approach perform quite well.

4 - Optimising the Design of Medical Screening Methods
Andrew J. Parkes, Grazziela Figueredo, Peng Shi

A common problem within healthcare is to design screening methods for potential disease conditions. Naturally, these methods need to be good at catching potential cases; however, they also need to avoid generating too many false positives, as this leads to further tests, raising patient anxiety and costs. Often the design of the test includes selection of relevant quantities, choice of thresholds on these, and a decision procedure for how these are combined. Altogether, these requirements generate a multi-objective optimisation problem; and that is furthermore closely linked with decision trees in machine learning. However, has differences in that the designed decision procedures need to be simple and understandable to clinical staff and patients. We discuss a particular problem in cancer screening, and describe recently-developed methods based on a hybrid of genetic algorithms and harmony search.

■ MD-31

Monday, 14:30-16:00 - G108

Decision support in healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Marion Penn*

1 - Scheduling Blood Donation Clinics to Match Supply and Demand
Emily Williams, Paul Harper, Daniel Gartner

Human blood is a scarce resource and its role in healthcare is fundamental, with donated blood saving the lives of many on a daily basis. The efficiency and timelines of the collection of blood from donors is crucial to the effectiveness of the blood supply chain. Working in partnership with the Welsh Blood Service, our aim is to match supply and demand of blood products, whilst minimising costs and wastage in the system. We present an integer linear program model that consists of two stages. The first stage schedules mobile blood donation clinics, considering over 500 locations, with the objective to minimise the number of clinics scheduled within the planning horizon. Constraints ensure that clinics are scheduled according to their estimated supply and the daily demand for blood. The second stage assigns staff to each scheduled clinic, with the objective of minimising costs. The model is solved using PuLP - an open source Python package which utilises COIN-OR CLP to solve the linear program.

2 - Modelling the Impact of Ferritin Testing in Blood Donors
John Blake

Blood donation has long been assumed to be innocuous, but recent papers, including studies conducted at Canadian Blood Services (CBS), suggest that frequent donation may negatively impact donor iron levels. One method for ensuring the health of donors is to monitor ferritin in repeat donors and provide counselling to individuals with low ferritin levels. Donors may also be temporarily deferred from blood donation until their iron reserves can be restored. The purpose of this study is to estimate the impact of ferritin testing on the CBS donor population; specifically, the number of donations expected, the number of tests conducted, and the number of donors identified as having a low ferritin level, under varying testing and deferral regimes. A simulation that mimics individuals who volunteer to donate blood was built, populated with operational data, verified and validated. A series of experiments was conducted in which donors were assumed to be tested after every fifth or every tenth donation. If donors are tested every fifth donation, approximately 21,400 fewer donations (likely range 13,500 - 21,400) are expected when compared to today with approximately 97,200 ferritin tests being conducted annually under this policy. If donors are tested every tenth donation, 8,500 fewer donations are expected when compared to today with approximately 40,500 ferritin tests being completed annually.

3 - Increasing implementation of OR projects in healthcare: our learning across a variety of projects
Marion Penn, Thomas Monks

Implementation of the results of operational research projects in healthcare has increasingly become a concern for academics in the field. This talk will discuss our progress in increasing implementation of OR modelling both within the original healthcare partner organisation, for whom modelling has been undertaken, and other organisations with similar problems. We will start with consideration of how our experience compares with the literature on implementation in healthcare. This will include both factors that increase the chances of implementation and barriers to successful implementation. We will then to explore our ongoing work to create 'simple' generic simulation models and make them publically available. If a model is sufficiently generic, then it can be used to study similar problems within the same organisation, or in other organisations. We will discuss the advantages and disadvantages of aiming to create generic models, as well as our ongoing work to distribute models and encourage their use.

■ MD-32

Monday, 14:30-16:00 - G109

Structural Bioinformatics

Stream: OR in Life Sciences
Invited session
Chair: *Agnieszka Rybarczyk*

1 - Web-Based Integrated Sequence and Structure Visualization
David Hoksza, Marek Ostaszewski, Piotr Gawron, Ewa Smula, Reinhard Schneider

The growing amount of available experimentally determined and predicted protein structures create an opportunity to interpret existing sequence data in the context of available three-dimensional structures. Although large-scale analysis combining sequence and structure data became possible due to the development of publicly available programming interfaces, an integrated visualization of the combined sequence and structure data was missing. Here we introduce Molart, a lightweight JavaScript tool enabling visual interpretation of sequence annotations in the context of available structural data. Given a UniProt ID, MolArt connects to public resources and retrieves corresponding sequence, sequence annotations, sequence-structure mapping and available experimental and predicted structures. This information is then available in a single, interactive visual display allowing to colour-overlay sequence features over the available 3D structure. MolArt is highly customizable, enabling users to provide their custom annotations, both on sequence and structure level. By providing a way to explore sequence and structure features in one display, MolArt enables life scientist to benefit from the wealth of molecular data existing in various databases, streamlining biological hypothesis generation.

2 - Ab Initio Evaluation of 3D Structural Model of Protein/RNA Molecule
Piotr Lukasiak, Tomasz Ratajczak, Thomas Villmann

The number of Protein/RNA 3D structures is growing exponentially because of the progress in available computational power. Currently, there are many tools and methods for the prediction of three dimensional structures of biomolecules and researchers are trapped in the huge amount of available data. Multiple candidate models can be generated by each tool, and each of them has to be evaluated, usually through manual inspection. Thus, selecting the best model (the model the most similar to the original one) becomes a crucial challenge. One can define the problem in a following way: given multiple models of a single real 3D structure, the proposed method should provide a ranking ordering those models by their distance from the reference structure. Each model should corresponds to a unique position in the ranking. Model quality position in the ranking is estimated based on the density distribution by comparing it with other models using particular similarity measure. The more models is taking into consideration, and the more methods are used, the ranking is more reliable. There is an additional assumption of independence of analyzed models generated by different prediction tools. Rankings constructed by proposed methodology were under evaluation using selected data sets from blind 3D prediction experiments (CASP and RNA-Puzzles) and proved its usefulness.

3 - Probabilistic Sampling of RNA 3D Conformational Space
Tomasz Żok

RNAs are molecules with many degrees of freedom in structural arrangement. Understanding the laws of RNA folding in vivo and repeating the process in silico is a challenging task, but one that brings high hopes for biotechnology and others. As the number of 3D structures solved experimentally rises, the development of knowledge-based methods gains momentum. For example, 3D fold prediction often involves simulation based on parameters inferred from experimental data. To simplify the process, coarse grained representations are used. Usually this means working on a subset of real or virtual atoms (e.g. center of mass). However, the same idea works equally good for any other 3D structure representation, including the trigonometric one. It is based on values of rotation (torsion) angles around chemical bonds. The coarse graining here uses a pair of pseudo-torsion angles: and . This concept was used to create a new method of simulation. Statistical distributions of and have been computed from experimental data conditionally on the dinucleotide suite (a classification of RNA shape). Additionally, a library of dinucleotides has been created which exhaustively covers the whole spectrum of variability in a pair of nucleotides. During simulation, the statistical distributions are sampled and matching dinucleotides from the library are used to create a 3D model of RNA. Its energy is then computed and model is accepted conditionally as in the Monte-Carlo scheme.

■ MD-33

Monday, 14:30-16:00 - Q005

Dynamics and Games I

Stream: Dynamics and Games
Invited session
Chair: *Paula López-Casado*

1 - Distributional and Transitional Effects of Taxes on the Macroeconomy in a Continuous-time Framework
Kenji Miyazaki

Using a Heterogeneous Agent Model in Continuous Time (HACT), we investigate the macroeconomic effects of changing tax rates on capital stocks and consumption. We especially focus on distributional and transitional effects. A Hamilton-Jacobi-Bellman equation for individual choices and a Kolmogorov Forward equation for the evolution of the distribution contribute to a dramatic improvement in computation speeds for solving continuous-time models. Our main numerical results are as follows. Raising taxes on capital decreases the level of capital and increases income and wealth Gini coefficients in the long run. Raising taxes on consumption has no effect on the level of capital in the long run, but gives a temporary over-accumulation effect,lowering income and wealth Gini coefficients.

2 - Joint optimization of inventory and promotions for platform-seller retail systems with dynamic stochastic demands
Hongyan Jenny Li

We address the inventory and rebate optimization problem for a platform-based retail system. The system consists of a retail platform who provides a sales channel and sellers who sell services/products and own inventories. The retail platform and the seller coordinate based on a rent plus revenue sharing contract. However, they make inventory and promotion (advertisement/rebate) decisions independently so that their local profit is maximized. The iterative promotions and dynamic stochastic demands are considered under the platform-lead Stackelberg game environment. We first analyze the single seller case as a benchmark so that the inventory and promotion schemes are optimized. Then, the problem is extended to consider the case of multiple sellers who sell substitutable items. The problem is formulated as stochastic programming models. The solution algorithms are proposed. Several research questions are addressed. For example, what is the optimal inventory level of the seller? Whether should a seller participate a promotion program or not? What are the optimal platform advertisement and product rebate in each period? The aim is to provide managerial insights on what roles the rebate plays under the coordination and competitive environment for the platform-based retailing systems.

3 - When do firms benefit from competition?
Zhengping Wu, Yiqi Sun, Wanshan Zhu

This talk considers the optimal decisions of firms under joint price and lead-time competition, and examines the impact of competition on firm profit. Surprisingly, we find that firms can benefit from competition under certain parametric conditions.

4 - A defined benefit pension plan as a stochastic differential game with Poisson jumps
Paula López-Casado, Ricardo Josa-Fombellida, Juan Pablo Rincon-Zapatero

This work presents a defined benefit pension plan as a two-player differential game. The surplus is invested in a portfolio based on bonds and risky assets. The highlight of this work is to consider the dynamic management of the pension plan in a financial market not only with Brownian but with Poisson jumps uncertainty. The aim of the firm is to maximize the utility of the surplus and the aim of the workers is to maximize a utility of the benefits, both in an infinite horizon. We find and analize Nash equilibrium strategies for the two player game and the optimal surplus evolution, by means of dynamic programming techniques adapted to non-cooperative game theory with jumps. Finally, we realize a sensitivity analysis of the optimal policies and the optimal surplus for several scenarios obtained varying the parameters of the model.

■ MD-34

Monday, 14:30-16:00 - Q006

Uncertainty and Robustness in Multiobjective Optimization

Stream: Multiple Criteria Decision Making and Optimization (contributed)
Contributed session
Chair: *Cristina Bazgan*

1 - Machine Learning for simulating unknown preferences in scenario-based multiobjective optimization
Babooshka Shavazipour, Kaisa Miettinen

Scenario-based multiobjective optimization (SBMOO) can deal with uncertainty in the absence of reliable probability distributions. However, using scenarios introduces an additional dimension, which brings more complexity. In all multiobjective optimization problems, a decision maker plays an important role. In most cases, for finding a preferred Pareto optimal solution, (s)he needs to provide preference information such as aspiration levels for each objective function. In SBMOO, we have a multiobjective optimization problem in each scenario and, thus, the elicitation of required preference information from the decision maker for all objectives in all scenarios can be very laborious or beyond human capabilities. In practice, we may need to settle for with incomplete preferences.

It is not straightforward to apply the existing approaches, developed for incomplete preference handling, to a high-dimensional problem such as SBMOO. In this research, we propose a method for treating the unknown preferences in SBMOO problems. The main idea is to simulate the decision maker's unknown preferences through utilizing machine learning tools in which the available preferences of the decision maker are used for initial training. In other words, machine learning tools are used to learn relationship between the ideal and nadir points and the decision maker's preferences.

2 - An iterative approach to robust multiobjective optimization
Fabian Chlumsky-Harttmann, Anita Schöbel

Various concepts of robustness for uncertain multiobjective optimization problems have been established in recent years. Though algorithms to find robust solutions still have to be developed. We focus on two robustness concepts for multiobjective optimization, namely point-based minmax robust efficiency, where solutions are evaluated by their worst-case in each objective, and set-based minmax robust efficiency, where for every solution the entire set of possible objective values is considered, and are inspired by well-known iterative cutting-plane approaches for single-objective robust optimization. Starting with a small set of scenarios, in every iteration we determine a robust efficient solution for a given uncertainty set and add one of its worst-case scenarios to the uncertainty set, thereby gradually increasing its size. Depending on the scenario added, the Pareto front changes. We investigate these changes and draw conclusions about the criteria to be used when a new scenario to be added is chosen.

3 - Reference Point Methods for Set-based Robustness by Means of the Hausdorff Distance
Carlos Ignacio Hernández Castellanos, Sina Ober-Blöbaum

In recent years there has been a growing interest in defining and studying multi-objective optimization problems under uncertainty. In particular, the set-based robustness allows the decision maker to analyze a given solution from the worst-case perspective. In this kind of problems, each solution in decision space maps to a set that represents the trade-offs of the worst possible scenarios.

To the best knowledge of the authors there exist only a few methods that aim for set-based robustness (mainly based on scalarizing functions). In this work, we extend the reference point methods where the decision maker defines an aspiration vector, and the task is to find the solution that minimizes the distance of its image to the aspiration vector.

Since we are dealing with a set-valued mapping, we use the Hausdorff distance, which is widely used to measure the distance between sets. Further, we prove that the method converges locally to an efficient solution for some aspiration vector. Finally, we test the method on an academic test function based on the Lamé superspheres where it is possible to observe the behavior the method.

4 - Critical elements for multiobjective optimization problems
Cristina Bazgan, Sonia Toubaline, Daniel Vanderpooten

In order to assess the resilience of a system consisting of several entities, it is important to evaluate its capacity to withstand the failure or destruction of some of its entities. It is then necessary to identify the critical entities of the system in order to protect them. In many contexts, the system can be modeled by a valued graph whose vertices or edges constitute the entities. One way to formulate the search for critical entities consists in identifying, among all subsets of vertices or edges of fixed size, a subset whose suppression would induce the strongest degradation of the measurement of performance or the largest increase in the cost of running the system (k most vital version). Another way is to determine the minimum number of vertices or edges to delete in order to achieve a certain level of performance or cost degradation (min-blocker version). We study the problem of determining the most critical elements (vertices or edges) for multi-objective optimization problems. We first present a multi-objective generalization of the min-blocker version defined as follows: Given a point b in the objective space, determine the minimum number of elements to be deleted such that there is no more feasible point dominating b. We also propose a multi-objective extension of the k most vital version. We present iterative algorithms to solve these versions and provide experimental results for the multi-objective selection and shortest path problems.

■ MD-35

Monday, 14:30-16:00 - Q009

Game Theoretical Models and Applications II

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Gustavo Bergantinos*

1 - Fair allocations for cooperation problems in vaccination
Evelot Westerink-Duijzer, Loe Schlicher, Marieke Musegaas

Vaccination is a very effective measure to fight an outbreak of an infectious disease, but it often suffers from delayed deliveries and limited stockpiles. To use these limited amounts of vaccine effectively, health agencies can decide to cooperate and share their vaccines. In this paper, we analyze this type of cooperation. Typically cooperation leads to an increased total return, but cooperation is only possible when this total return can be distributed among the players in a fair way. Using cooperative game theory, we derive theoretical conditions under which cooperation is possible and we show that the resources can be traded for a market price in those cases. We perform numerical analysis to generalize these findings and we derive analytical expressions for market prices that can be used in general. Our results demonstrate that cooperation is a delicate matter. It is most likely to be possible when the total amount of resources is limited or very large. When cooperation is possible, trading resources for a market price often results in a fair allocation of the total return. A case study on the redistribution of influenza vaccines confirms these findings.

2 - On the nucleolus of the irreducible form of a minimum cost spanning tree game
Leanne Streekstra

Minimum cost spanning tree (m.c.s.t.) problems study how to connect a group of agents efficiently to a source, when the cost of implementing an edge is fixed. After an efficient tree has been found, the subsequent question is how to allocate the total cost among the agents involved. One well-studied solution for this problem is the so-called folk rule, which applies the Shapley value to the largest reduction of the cost matrix that does not lower the cost of an efficient tree (the irreducible cost matrix). In this paper we introduce a new cost sharing solution for m.c.s.t. games; the nucle- olus applied to the irreducible cost matrix. Unlike m.c.s.t. games in general, the game associated with the irreducible cost matrix of a m.c.s.t. problem is concave. As this means that the minimum excess over all coalitions, given an allocation can be computed in polynomial time, the nucleolus of such games can be computed efficiently as well (Faigle et al., 2001). We study the axioms satisfied by this new cost sharing solution and compare it with the axiomatization of the folk rule (Bergantiños and Vidal-Puga, 2007). Bergantiños, G., & Vidal-Puga, J. J. (2007). A fair rule in minimum cost spanning tree problems. Journal of Economic Theory, 137(1), 326-352. Faigle, U., Kern, W., & Kuipers, J. (2001). On the computation of the nucleolus of a cooperative game. International Journal of Game Theory, 30(1), 79-98.

3 - Uncertainty in information markets
Silvia Miquel, Saadia El Obadi

Information market games (Muto et al., 1989) try to model the trading of information between an informed firm, the patent holder, and other initially not informed firms. The maximal profit attainable in each submarket, where a new product is manufactured, is obtained by the set of firms that control that submarket provided the informed firm has entrance to it. The model considers the profit attainable in each submarket as data of the problem. However, in general, it cannot be known exactly. Therefore, we address the uncertainty problem by considering the maximal profit of each submarket as an interval. The aim of this contribution consists in providing solutions for sharing the profits obtained in the market under uncertainty. Such solutions provide an interval of payoffs to each player, such that the maximal profit all players can obtain together by cooperation is allocated among the players.

4 - A family of rules to share the revenues from broadcasting sport events
Gustavo Bergantinos, Juan D. Moreno-Ternero

We consider the problem of sharing the revenues from broadcasting sport league events, introduced by Bergantiños and Moreno-Ternero (2018). We characterize a family of rules compromising between two focal and somewhat polar rules: the equal-split rule and concede-and-divide. The characterization only makes use of three basic axioms: equal treatment of equals, additivity and maximum aspirations. We also show further interesting features of the family: (i) if we allow teams to vote for any rule within the family, then a majority voting equilibrium exists; (ii) the rules within the family yield outcomes that are fully ranked according to the Lorenz dominance criterion; (iii) the family provides rationale for existing schemes in real-life situations.

■ MD-36

Monday, 14:30-16:00 - Q010

Selected Topics in Vehicle Routing and Logistics Optimization

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Daniele Vigo*
Chair: *Luca Accorsi*

1 - Enhancing Local Search Through Machine Learning: a Case Study on the Vehicle Routing Problem
Daniele Vigo, Luca Accorsi, Michele Lombardi, Michela Milano

Local search is one of most popular optimization techniques used to effectively solve hard combinatorial optimization problems (COPs) and in particular large scale ones, for which exact solution approaches are prohibitive.Local search is indeed the main engine of all modern metaheuristics which perform hundreds of thousands of iterations exploring the neighborhoods of given solutions. Practical algorithms typically exploit a relatively small set of simple local search operators and use them to optimize a solution until a local optimum is reached. A common example of such apporaches is the Variable Neighborhood Descent (VND), in which the neighborhood defined by each operator is completely examined before moving to the next operator. Up to now, little attention has been given to the orderings in which operators are examined; common orderings usually consists in prefixed static or dynamic randomly ordered operators examination. This work we study whether in a VND setting, using Machine Learning techniques to identify the most promising operator (or knowing that none of them will be able to improve a given solution) enables computational savings that could be used to perform a more fruitful search. In particular, as a case study, we focused on the (capacitated) vehicle routing problem, and we train an Artificial Neural Network for raking operators at search time.

2 - Two models for the yard crane scheduling problem in a port container terminal
Jose M. Belenguer, Ramon Alvarez-Valdes, Eva Vallada, Fulgencia Villa

In this work, we study a problem arising at a container terminal, consisting of scheduling a yard crane to carry out a set of container storage and retrieval requests in a single container block with multiple input/output points located at both the seaside and the landside. We have to schedule the containers in the crane and, simultaneously, to assign an input/output to each container, taking into account the possible congestion in both sides of the block. The objective function is a weighted combination of the delays, taking into account the time in which a container arrives to the block to be stored and the time in which a container in the block is required at the seaside or landside. Two mathematical models are developed for this problem, considering it as a routing problem and as a machine scheduling problem. Benchmark instances are also proposed and used to test models.

3 - The Consistent Vehicle Routing Problem with heterogeneous fleet
Foteini Stavropoulou

Customer services offered by numerous companies require that employees (service providers) visit customers on a regular basis. Consistency in the routing plans is a highly desirable feature as it enhances brand loyalty and customer satisfaction by allowing the service providers to develop relations and create bonds with the customers. Different types of consistency have been defined and discussed in literature, i.e. time consistency, person consistency and delivered quantity consistency. The existing variants of Consistent Vehicle Routing Problems (ConVRPs) assume that an unlimited number of identical vehicles is available at a central depot. However, in most practical applications a vehicle fleet is likely to be heterogeneous and of limited size. This paper introduces the ConVRP with heterogeneous fixed fleet (ConVRPHFF). The objective is to determine the vehicle routes that minimise fixed and variable costs, given a depot-returning heterogeneous vehicle fleet of fixed size, while offering consistent customer service. A new mathematical model is proposed and a metaheuristic method is designed for this new complex problem.

■ MD-37

Monday, 14:30-16:00 - Q011

Scheduling with Resource Constraints: Manufacturing and Logistics

Stream: Scheduling with Resource Constraints
Invited session
Chair: *Mark Baxendale*
Chair: *Gur Mosheiov*

1 - Machine-based Production Scheduling for Rotomoulded Plastics Manufacturing
Mark Baxendale

Minimising total tardiness in a multi-machine rotomoulded plastics manufacturing plant is considered. The problem may be generalized to hybrid flow shop scheduling with batching, where additional constraints are required to control which machines may be used at each stage. The problem is formulated as a mixed integer program which is shown to be NP-hard. Consequently, simulated annealing and tabu search algorithms were developed in conjunction with a constructive heuristic to obtain near-optimal solutions within a practical time-frame. A comparison of metaheuristic solution methods was performed using randomly generated problem instances containing varying numbers of jobs.

2 - Collaborative job scheduling in the wine bottling process

Franco Basso, Mario Guajardo, Mauricio Varas

This paper proposes a horizontal collaborative approach for the wine bottling scheduling problem. The opportunities for collaboration in this problem are due to the fact that many local wine producers are usually located around the same region and that bottling is a standard process. Collaboration among wineries is modeled as a cooperative game, whose characteristic function is derived from a mixed inte- ger linear programming model. Real world instances of the problem are, however, unlikely to be solved to optimality due to its complex combinatorial structure and large dimension. This motivates the intro- duction of an approximated version of the original game, where the characteristic function is computed through a heuristic procedure. Unlike the exact game, the approximated game may violate the subad- ditivity property. Therefore, it turns relevant not only to find a stable cost allocation but also to find a coalition structure for selecting the best partition of the set of firms. We propose a maximum entropy methodology which can address these two problems simultaneously. Numerical experiments illustrate how this approach applies, and reveal that collaboration can have important positive effects in wine bot- tling scheduling decreasing delay by 33.4 to 56.9% when improvement heuristic solutions are used. In contrast to the exact game in which the grand coalition is always the best outcome, in the approximated game companies may be better forming smaller coalitions.

3 - Scheduling k shuttles in a shared-storage automated storage and retrieval system

Lukas Polten, Simon Emde

In this talk we study a shared-storage automated storage and retrieval system (AS/RS) with one crane capable of carrying multiple unit loads. We develop a new mixed integer linear programming formulation and a novel branch and price algorithm with both exact and heuristic column generation methods. We test the effectiveness of our proposed methods and demonstrate its effectiveness. We then use these methods for a simulation of different AR/RS systems to derive multiple novel managerial insights. We show that the relation of total processing time and capacity of the shuttle can be predicted by a simple rule. We also determine the optimal shape for a shelve.

4 - On hard scheduling problems with generalized due-dates

Gur Mosheiov, Enrique Gerstl

In scheduling problems with generalized due-dates (gdd), the due-dates are specified according to their position in the sequence, and the j-th due-date is assigned to the job in the j-th position. In this paper, we study a number of problems with gdd. We focus first on the classical objective of minimizing the number of tardy jobs on parallel identical machines. In our knowledge, no solution procedure has been proposed in the literature to this NP-hard problem. We introduce an efficient pseudo polynomial dynamic programming (DP) algorithm, and our numerical tests indicate that large instances are solved to optimality very fast. For example, the worst case running time required for solving a 2-machine 1000-job problem does not exceed 1 second. We also extend our proposed DP to a setting of uniform machines, i.e., to the case that machines have different speeds. The computational effort required by the modified DP appears to remain almost unchanged. Another objective considered here is that of maximizing the number of jobs completed exactly on time on a single machine (max-on-time). We prove that this problem is NP-hard in the strong sense. In our knowledge, this is the only example of a scheduling problem, where the job-specific version has a polynomial time solution, and the gdd version is strongly NP-hard. An efficient heuristic and a branch-and-bound algorithm are introduced and tested.

■ MD-38

Monday, 14:30-16:00 - Q012

Preferences and Pairwise Comparisons 1

Stream: Multiple Criteria Decision Aid
Invited session
Chair: Matteo Brunelli

1 - On the Preservation of Order and Intensity of Preferences of Inconsistent Pairwise Comparisons Matrices

Jiri Mazurek, Jaroslav Ramik

The aim of this paper is to examine the preservation of the order of preferences (POP), the preservation of the order of intensity of preference (POIP), and the fundamental selection (FS) condition for inconsistent pairwise comparison matrices (IPCMs), where IPCMs are divided into several categories with respect to a satisfaction or violation of the FS, POP, and POIP conditions. This approach is more suitable than Saaty's categorization (division) of IPCMs based on the value of the consistency index C.I. (consistency ratio C.R.). Further, a non-linear optimization method for the derivation of weights from an IPCM that guarantees the POP, POIP and FS conditions are met, is proposed. In the numerical part of the paper it is examined how frequently are the FS, POP and POIP conditions satisfied, or violated respectively, for randomly generated (via Monte Carlo method) pairwise comparison matrices.

2 - A mixed-integer linear programming problem for preservation of order preference condition

Bice Cavallo

This research deals with a crucial step in multi-criteria decision analysis, that is to obtain coherent weights for alternatives/criteria that are compared by means of a Pairwise Comparison Matrix (PCM), i.e. weights that preserve the order of the preferences expressed by the Decision Maker.

In order to obtain general results, suitable for several kinds of PCMs proposed in literature (e.g. multiplicative, additive and fuzzy), the research focuses on PCMs defined over a general unifying framework, that is an Abelian linearly ordered group.

Firstly, we provide a condition ensuring coherent weights. Then, by focusing on additive PCMs, we provide and solve a mixed-integer linear programming problem in order to obtain the closest PCM, to a given PCM, ensuring coherent weights. Isomorphisms and the mixed-integer linear programming problem allow us to solve an infinity of optimization problems, among them optimization problems concerning multiplicative and fuzzy PCMs.

3 - Bases and Coordinates for Pairwise Comparison Matrices

Michele Fedrizzi, Matteo Brunelli

We assume that pairwise comparison matrices are constructed in the additive representation of preferences. Then, as it is known, both the set of reciprocal matrices and the set of consistent matrices are vector spaces. We investigate the problem of defining suitable bases and the corresponding coordinates in such vector spaces. We prove that it is possible to define bases where the coordinates of each pairwise comparison matrix have an intuitive and clarifying meaning. We show that the orthogonal complement of the subspace of consistent matrices plays a crucial role in this study. Finally, we propose several numerical examples in order to demonstrate the effectiveness of our approach in better understanding the role of consistency in the pairwise comparison method.

4 - Supporting decisions by unleashing multiple mindsets using pairwise comparisons
Michele Lundy, Salvatore Greco, Sajid Siraj

Inconsistency in pairwise comparison judgments is often perceived as an unwanted phenomenon and researchers have proposed a number of techniques to either reduce it or to correct it. We consider spanning trees analysis which is a recently emerging idea for use with the pairwise comparison approach that represents the plurality of mindsets in terms of a plurality of prioritisation vectors. Until now, the multiplicity of prioritisation vectors supplied by the spanning trees approach have been amalgamated into a single priority vector, losing the information about the plurality of mindsets. With this in mind, we propose a novel methodology taking an approach similar to Stochastic Multi-criteria Acceptability Analysis. Considering all the rankings of alternatives corresponding to the different mindsets, our methodology gives the probability that an alternative attains a given ranking position as well as the probability that an alternative is preferred to another one. Since the exponential number of spanning trees makes prohibitive their enumeration, we propose computing approximate probabilities using a statistical sampling of spanning trees. Our approach can also be applied to incomplete sets of pairwise comparisons. We demonstrate its usefulness with a didactic example.

■ MD-39

Monday, 14:30-16:00 - Q014

Handling non-productive breaks in scheduling and project management

Stream: Project Management and Scheduling
Invited session
Chair: *Rubén Ruiz*

1 - Single-Machine Batch Scheduling to Minimize the Total Setup Cost in the Presence of Deadlines
Dominik Kress, Maksim Barketau, Erwin Pesch

We address the single-machine batch scheduling problem with the objective of minimizing the number of setup operations. This problem arises when there are n jobs that are partitioned into F families and when setup operations are required whenever the machine switches from processing a job of one family to processing a job of another family. We assume that setups do not require time but are associated with a fixed cost which is identical for all setup operations. Each job has a processing time and an associated deadline. The objective is to schedule all jobs such that they are on time with respect to their deadlines and the total setup cost is minimized. This is identical to aiming to minimize the number of setup operations. We show that the decision version of this problem is NP-complete in the strong sense. Furthermore, we present properties of optimal solutions and an O(n log n + nF) algorithm that approximates the cost of an optimal schedule by a factor of F. The algorithm is analyzed in computational tests.

2 - Scheduling of Maximizing Total Job Value with Job Selection
Eun-Seok Kim

In this talk, we consider a scheduling problem with job selection. The objective of this problem is to maximize the total value of selected jobs where the value of each job is given as a non-increasing step function of its completion time.

We first study several properties for an optimal solution, and based on these properties, we develop a branch-and-bound algorithm and a heuristic algorithm for the problem. Finally, we evaluate these algorithms in various settings, and the results show that they provide efficient and effective solutions.

3 - Exact approaches for scheduling problems: Mixed integer vs. constraint programming
Rubén Ruiz, Bahman Naderi, Vahid Roshanaei

Recently, the effectiveness of Constraint Programming (CP) solvers has been examined for a myriad of problems. CP models have been known for producing high-quality integer solutions but at the same time, they are notoriously known for the lack of bounds due to the lack of bounding mechanisms in their underlying tree search methods. On the other hand, modern solvers are nowadays capable of high-quality solutions when dealing with mixed integer models. Last year, CPLEX 12.8 was released with a variant that guarantees bounds and optimality gaps for integer solutions found by the CP solver. As a result, CP can be viewed now as a comparable alternative to traditional branch and bound methods. In this work we compare the MILP solver and the CPoptimizer of CPLEX. We study the traditional flowshop problem as well as some of its variants: hybrid flowshop, non-permutation flowshop and different objective functions as well. The results are surprising both in the size of instances that can be solved and also in the sheer performance obtained by the CP solver.

4 - Overcoming Coordination Barriers in Complex Product Systems Projects: The Imbrications of Technology Materiality and Social Action
Mohamed Benmerikhi

Complex product systems (COPS) projects feature coordination challenges which give rise to coordination barriers. These are problems that hinder the progress of work between interdependent actors, resulting in coordination breakdowns. Shedding light on coordination barriers improves our understanding of coordination phenomena in COPS projects with the view of enhancing their performance, which is currently unsatisfactory. This paper challenges the predominant view that coordination problems are merely inherent to organizational action. It draws on a knowledge perspective and a qualitative longitudinal design to emphasize the relevance of knowledge in coordination. Our case analysis focuses on the production of a COPS first prototype in a geographically dispersed project partnership form. We adopt sequence analysis to unravel distinct types of knowledge barriers namely, syntactic, semantic and pragmatic ones, and we outline how they are overcome by project actors in situations of new knowledge creation. The analysis further highlights organizational barriers manifesting alongside knowledge barriers at specific sequences. We observed an imbrication of artifacts and social actions where actors use, acquire and create different artifacts flexibly and in an ad-hoc manner to overcome coordination barriers. This analysis adds to existing research on COPS projects by treating knowledge as part of coordination dynamics. In particular, our case analysis provides empirical support for t

■ MD-40

Monday, 14:30-16:00 - Q015

Container Management

Stream: Maritime Transportation
Invited session
Chair: *Xinjie Xing*

1 - Defining internal container transfer paths in a maritime terminal through mathematical programming and discrete-event simulation
Rina Mary Mazza, Luigi Di Puglia Pugliese, Francesca Guerriero, Pasquale Legato

A grid-based model is used to represent the internal transfer operations between the crane and yard areas in a real container terminal bearing a Manhattan-like layout of the storage blocks. The objective is to determine the best route for every single container transfer performed by a fleet of shuttle vehicles, while accounting for route capacity, actual vehicle speed and distance to be covered. Thus, the problem of finding the optimal path between two vertices (i.e. an origin node and a destination node) in a multi-weighted graph is presented as a tailored mathematical program. Solution approaches for real-sized problems are investigated through a companion simulation model that embodies two alternative vehicle routing policies: an A-star global search technique based on an improved cost estimation heuristic; a local search technique that mimics the vehicle en-route behavior at every intersection-decision point. Numerical comparisons are presented.

2 - A VNS approach to Container Loading Problems with logistics constraints
Iván Giménez-Palacios, Maria Teresa Alonso Martínez, Ramon Alvarez-Valdes, Francisco Parreño

In recent years, logistics has become increasingly important in the business world as a way to save costs when shipping goods. However, at least in the Container Loading Problem, which is the one we are going to deal with, many restrictions that have a real application have not been studied in depth. In some cases we need to establish a priority when loading the container. This restriction is known as loading priority. In addition, in some types of companies, the products to be shipped may be packaged in different boxes and it makes sense to consider them as a single shipment, i.e., if one of these boxes is loaded, the rest of the boxes of the same order must also be loaded. Similarly, if one box is left out, the rest of the boxes in the order will be left out. This restriction is called complete shipment. So, in this paper we consider these two restrictions, which have been studied separately and as a whole, but considering not only the total volume of cargo but also the partial volume loaded of priority shipments, to establish an order of preference in the solutions. To do this, we use a construction based on maximal spaces with the neighborhood structure VNS to perform a local search. To test the algorithm with the new restrictions we will use the modified Bischoff and Ratcliff instances to include priorities and to create orders with multiple packages.

3 - Joint optimisation of tank container over-holding policy and dynamic operation of tank container management
Xinjie Xing, Dongping Song, Paul Drake

This research integrates the optimisation of customer over-holding policies and daily operational policies in tank container (TC) operations management. In this market, TCs are used not only for transportation tasks, but commonly as storage equipment for customers' production purposes. Similar to detention and demurrage (D&D) in the dry container (DC) market, such phenomenon brings extra profit to the TCOs (similar to D&D influence), but raises negative impacts which distort overall container flows, increase uncertainties and decrease operational profitability. To address this problem, a two-stage time-space network model is constructed. It aims at optimising the TC over-holding policies at higher level as well as improving operational level decision-making abilities. With the help of progressive hedging algorithm and mixed integer optimisation techniques, this research is able to not only effectively respond to the underlying research problem but also solve the problem with stochastic setting in a tractable manner. In addition, different sensitivity analyses were carried to demonstrate a series of insights for the use of industrial practitioners.

4 - Competition between liner shipping companies: the role of the Ultra Large Containership
Nemanja Milovanovic, Rommert Dekker

Over the past decades, containerships have rapidly grown in size. Nowadays, ships are being built that can accommodate over 22,000 TEU. This trend of continuously ordering bigger and bigger ships in order to pursue economies of scale has led to a market overcapacity. As a consequence, liner shipping companies have difficulties to capture enough demand to make these bigger ships cost-effective. Combined with a highly competitive market, liner shippers in general only see small profit margins, if any. In our research, we investigate the seemingly irrational behavior of continuously ordering bigger and bigger ships. We model the problem as a two-player competition, where both players decide on their rates and their liner network. We look at two settings. In the first setting, the players are identical liner shipping companies. In the second setting, we grant one player the possibility to use an ULCS. Furthermore, we compare the effect of fuel price changes and other factors between the two settings.

■ MD-41

Monday, 14:30-16:00 - Q013

Advances and Challenges in Multimodal Mobility

Stream: Public Transportation I
Invited session
Chair: Michael Redmond

1 - Bus Rapid Transit: Blessing or Curse for Africa?
Marianne Vanderschuren, Sekadi Phayane

The past decades has seen a boom of Bus Rapid Transit Systems (BRT) around the world. Curitiba and Bogota are cited as early prime examples of the system. In the African, more specifically the South African context, BRT has not lived up to its promise. Capital costs are high and operation subsidies are unaffordable for Municipalities with ever growing populations, aging civil infrastructure and limited budgets. This paper provides an overview of challenges faced by BRT systems in Africa. Based on an analysis of the first phase, operating, BRT system for the City of Tshwane - an alternative approach to BRT implementation is suggested, for future planned roll outs.The efficiency of various BRT elements were investigated and the impact they have on passenger demand, capital implementation time and cost. The impact of vehicle technology, fare payment before boarding, full Right of Way (ROW), as well as station distances were all computed to determine the effect they have on passenger attraction. Furthermore, traditional BRT, which offers full ROW, high-end services, enclosed high-quality stations, pre-boarding fare collection, frequent and rapid services, modern clean vehicles, branding and marketing, as well as a generally superior customer service - was compared to a BRT lite service, based on some form of priority, but no fully segregated bus lanes and instead of stations, simpler bus shelters. A prioritisation model was then developed, which looked at various criteria.

2 - Finding Reliable Itineraries for Multimodal Travel within Public Transit Networks
Michael Redmond, Ann Campbell, Jan Fabian Ehmke

Multimodal travel requires the combination of several transportation options to help the traveler get to his or her destination. Multimodal travel requires the combination of individual transport options, and it is not obvious what the overall reliability of combining several transport options is. In this presentation, I will discuss modeling and applying reliability measures to various itineraries throughout a multimodal travel network. This network may include scheduled travel modes such as metro or buses as well as non-scheduled travel modes such as biking or taking a ride-sharing service to bridge the first or last mile. We focus our reliability measure on making it from the origin to destination within a travel time budget through these multimodal networks.

The novelty of this problem arises with missed connections in a scheduled network, as the wait time and travelling to other stops/nodes complicates the probability distributions. Our research covers how the evaluation of different itineraries is handled so that it is mathematically accurate and easy to understand for travelers. The aim of this research is to give information to travelers outside of the current shortest-path scope to improve transparency and decision-making in the public transit system.

3 - Multimodal routing with time-dependent taxi lifts
Vassilissa Lehoux, Christelle Loiodice, Darko Drakulic

During the last decades, cities have spread widely, increasing the attraction of large metropolis toward nearby cities and peripheral zones.

It led to a diversification of transportation offer in suburban areas in particular, with taxi like on-demand public transportation or new ride-haling services. However, most routing applications are not proposing to combine those rides with public transit and people are let with the burden of finding good combinations. In this work, we focus on computing itineraries using taxi at the beginning or the end of the path to reach public transit, hence avoiding congestion in the city and travelling at a cheaper rate than a complete ride. However, building good itineraries combining taxi and public transit is expensive compare to walking or riding a bicycle as the number of stations that can be reached from a point is far more. We propose a model that compares the inconvenience of taking a taxi to a number of transfers between trips depending on the taxi travel distance. In this setting, our resolution method computes Pareto optimal paths for earliest arrival time and profile queries with number of transfers as a second criterion. It extends the Trip Based Public Transit Routing algorithm [1]. An efficient pruning is also proposed to speed up the search. Tests are performed on the Korean network with historical traffic conditions. [1] S. Witt. Trip-Based Public Transit Routing. In Algorithms - ESA 2015, Berlin, Heidelberg, 1025-1036, 2015

4 - A Solution-Space Sampling Approach to Guide Travelers in Multimodal Routing
Jan Fabian Ehmke, Thomas Horstmannshoff

Digitalization enables travelers access to an ever-increasing number of mobility services. Combining these services to create door-to-door multimodal travel itineraries is challenging due to the diverse set of characteristics of scheduled and non-scheduled mobility services. To identify a traveler's individual set of relevant itineraries, travel websites use multimodal shortest path approaches. They also offer simple sorting and filter capabilities to let travelers reduce or extend the retrieved set of itineraries. However, due to the complexity of the underlying search space, it is challenging for the traveler to adapt the created set of multimodal travel itineraries in a systematic way. In this presentation, we propose a solution-space sampling approach to derive request-specific meta-information about the solution space of multimodal travel itineraries. This information is required to guide travelers in creating individually optimal sets of multimodal routes. We also present an approach to determine information about reasonable parameter settings. In particular, we derive information about intervals of and relationships between travel parameters by systematically parameterizing single and multi-objective multimodal shortest path optimization. In a laboratory setting, we exemplify and examine solution-space sampling using data from scheduled and non-scheduled mobility services from the German transit network.

■ MD-42

Monday, 14:30-16:00 - Q113

Freight transportation and logistics I

Stream: Transportation
Invited session
Chair: Daniel Nicola

1 - Analyzing liner shipping routes from Asia to Europe for when the Northern Sea Route becomes a viable commercial alternative
Allen Zhou, Po-Hsing Tseng, Feng-Jang Hwang

In recent years, the Northern Sea Route (NSR) has been widely discussed in the shipping industries since it may bring economic benefits resulting from its shorter sailing distance vis-a-vis the conventional route via the Suez Canal. Concomitantly, given the pressure of green routing and scheduling development, how to effectively deploy shipping fleet and fit environmental external costs threshold has become increasingly important issues in the shipping industries. In this study, a mixed integer linear programming model is used to analyze multi-port trip liner service in the Asia-Europe container shipping network. The objective function is to minimize the total cost which includes operational costs to the shipping business and external emission costs to the environment. Based on estimated data of NSR shipping, ship routing schemes on both the NSR and conventional routes are proposed.

2 - A combinatorial auctions based method for the procurement of crowd-shipping in transportation networks
Chefi Triki

Introducing crowd-shipping in the context of freight transportation can represent a valuable option in order to face some of the distribution challenges. This work is concerned with improving the orders delivery by involving occasional drivers to be selected from the public using the combinatorial auctions technique. We propose a mathematical model that is based on integrating the routing of vehicles with the winner determination problem. The objective is to minimize the overall transportation cost due to either the company's own fleet or by external drivers. The validation of the model as well as the advantage of involving occasional drivers have been verified by solving a real case study related to a delivery company.

3 - Municipal solid waste collection: Fleet composition, scheduling and routing
Dušan Hrabec, Jorge Oyola, Richard Hartl

In our paper, we study waste collection problem where routing, fleet composition and collection schedule have to be optimized in order to minimize the total operational costs. The collection network composes of multiple types of waste while each container has to be visited with a specified weekly collection frequency. The fleet composition decision is made over a set of heterogeneous single-compartment vehicles. The problem is formulated as a multi-trip multi-commodity heterogeneous fleet composition periodic vehicle routing problem. A general mathematical model of the problem is presented and a solution algorithm is proposed. Computational results are presented on an illustrative data sample (with regards of a future usage of the proposed approach on a real case study in the Czech Republic). The problem is solved by the developed heuristic method as well as by exact methods in order to test the suggested waste collection approach (i.e., model as well as proposed algorithm).

4 - Collaborative Transportation Mechanisms: A Request Exchange Approach
Daniel Nicola

In this paper, we present frameworks for auctions-based and non auctions-based mechanisms for the exchange of requests between carriers that are members of a collaborative network, operating in the same geographical areas. The main objective is to give carriers the chance of improving their original sets of requests, so they decrease the distances traveled by their vehicles and increase their efficiency. Because of the nature of routing problems, requests usually have different costs for different carriers, depending on the location of the depots and also on the other requests that have to be serviced. The exchange mechanism should then find a new allocation, in such a manner that carriers obtain requests that have more value (or less cost) for them. Besides the detailed description for every single mechanism, we provide an analysis of special considerations that have to be taken into account in the design of the mechanism's processes. All mechanisms are tested on a same scenario, and from comparing their results, we look for a better understanding of their behavior that allows us to obtain insights for their application.

■ MD-43

Monday, 14:30-16:00 - Q114

Facility location in supply chains

Stream: Location Analysis and Optimization
Invited session
Chair: Mozart Menezes

1 - Joint optimization of supply chain network design and finance
Olivier Péton, Hamidreza Rezaei, Nathalie Bostel, Vincent Hovelaque

Many suppy chain design models aim at planning the deployment of logistics network over time while minimizing a sum of logistics costs. While doing this, they omit another strategic decision: how to finance new facilities.

The design and implementation of a supply chain usually proceeds through successive stages: design, engineering, purchase of land and procurement, construction and commissioning. Each of these stages requires the provision of funds. Thus, planning the availability of these funds goes hand in hand with the supply chain design decisions.

We propose a mathematical model for supply chain design, integrating financial decisions related to the construction life cycle. With an international context, one strong feature of the model is the possibility to locate financial decisions such as long term debts, marketable securities transactions and pledging. The objective function is to maximize the corporate value of the company after a time period of a few years. We present the results of computational experiments on a set of generated instances solved with IBM Cplex solver. We show how the integration of logistics and financial considerations impacts the determination of optimal supply chains.

2 - Long term mine planning and metallurgical plant location for a rare earth project: Minera Biolantánidos
Pablo González-Brevis, Cristian Palma

Mine planning determines which and when should the orebodie zones be mined and where to send the extracted material (metallurgical process or dump). In the decision, it must be considered that there are zones that give better yield than another because they have a higher ore grade. Also, there are zones that must be mined before than others to guarantee operation feasibility. On the other hand, if the metallurgical plants have to be constructed, their locations must be determined and this decision will impact the project costs directly. In order to maximize the net present value (NPV) of a mining project of these characteristics one should consider the long term mine planning and the metallurgical plant location at the same time, which is a complex task. In this talk will be present a mixed integer linear optimization model which considers the aforementioned situation while maximizing the NPV of a rare earth mining company: Minera Biolantánidos (Chile). The benefits of using a modular plant scheme instead of fixed plants will also be discussed.

3 - A location-production model for preprocessing facilities in a waste recovery tires network
Eli Angela Toso, Jorge Michael Burgos Meneses, Deisemara Ferreira

Waste tires disposal in Brazil is regulated by an environmental legislation that requires producers and importers to take responsibility for collecting and recovering end-of-life tires. The current reverse network is made up of collection points, preprocessing, and recovery facilities. The collection points receive used tires and send them to be preprocessed or directly [?] to be recovered. In preprocessing facilities tires are sorted into usable and waste: the usable ones can be sold to second hand market; waste tires are processed to separate metal and textile materials and they can be shredded before being sent to recovery. Recovery facilities include recycling and energy recovery companies with different costs to process used tires. Some recovery companies receive either whole or shredded tires, depending on its re-utilization purpose. In this context, we propose a mathematical model to support decisions involved in used tires reverse logistics: opening new preprocessing facilities, the production planning in these plants, and, the flow of whole and shredded tires among facilities. Tests with Sao Paulo State real data show that opening new preprocessing facilities can improve the recovery network for several stakeholders, increasing the number of tires sent to reuse, reducing transportation and disposal costs.

4 - Dual SKU Rationalisation and Location Problems: Locating Facilities for Heterogeneous Customers
Mozart Menezes, Diego Ruiz-Hernandez

Different customers induce different production costs to each stock keeping unit(SKU). Differences originate mostly from typical production lot sizes, which in their turn induce different efficient use of the production capacity available. Therefore, firms operating in a business-to-business (B2B) environment, where the number of each facility customers are measured in hundreds in contrast with thousands or millions in a business-to-customer environment, need to consider customers' order lot size profile when calculating profit contribution of each SKU. Departing from traditional fixed-costs allocating mechanisms, we introduce a facility location model for a B2B environment where fixed-costs are incurred when opening a facility and operating efficiency depends on the specific production jobs assigned to that particular facility. In this way, two problems are tackled simultaneously: SKU rationalisation and the capacitated facility location problems. Using real data, we find that resulting solutions have less capacity, higher capacity utilisation, smaller and fewer facilities than current network design. Serving demand from closest facility is likely but not necessarily a biding constraint. Furthermore, in most real cases analysed we found a substantial increase in operating profits when using the approach proposed.

■ MD-44

Monday, 14:30-16:00 - Q115

Non-Standard Optimization Methods

Stream: Non-Standard Optimization and Decision-Making Methods
Invited session
Chair: Martin Gavalec

1 - Tolerable interval eigenvectors in fuzzy algebra
Daniela Ponce, Martin Gavalec, Ján Plavka

In max-min fuzzy algebra, the standard pair of operations—plus and times—is substituted by a different pair of operations—maximum and minimum—, which are involved in many optimization problems. Investigation of the properties of eigenvectors is important for these applications.

The values of vector or matrix inputs in practice are usually not exact numbers and in some intervals they can instead be considered as values. This paper investigates the properties of matrices and vectors with interval coefficients. The research is concentrated to tolerable eigenvectors.

Three basic types of tolerable interval eigenvectors of an interval matrix in max-min fuzzy algebra can be found in the literature. For the strongly tolerable type, the structure of the corresponding eigenspace and the efficient recognition algorithms have been described in an earlier paper of the authors. The similar solution for the remaining two types—tolerance and weak tolerance—of the interval eigenproblem in max-min algebra are briefly presented in this contribution. In addition, the computational complexity of the results is shown and illustrative examples are given.

Support of the Czech Science Foundation GAČR 18-01246S is gratefully acknowledged

2 - Marketing Campaign Performance Measurement by Return Of Investment: A Fuzzy Set Approach
Sarka Krizkova, Martin Gavalec

This paper suggests a new method for estimating Return of Investment (ROI) based on evaluating every customer in the marketing funnel using the fuzzy theory approach. Knowing the ROI helps organisations to not only evaluate their marketing campaign but optimise the results and allocate their budget more effectively or as a marketing agency, then estimating ROI provides the real value for your client. For both, companies and agencies, it is hard to calculate exact ROI because some variables can't be measure by the usual techniques. This method is based on the idea that we can easily define hard-to-measure variables using knowledge of marketing funnels and a marketing strategy. Looking at the funnel we can easily define five stage - awareness, interest, consideration, intent and purchase. This article proposes a fuzzy inference model to estimate different values of each customer and subsequently this estimation is used to calculate ROI. Using this knowledge and what we can learn about each customer, fuzzy rules can be created and used to create a robust fuzzy inference system. The model therefore synthesis metrics such as control variables (what is influencing traffic), different marketing strategies, first/last touch source. This model will make it easier and more efficient to define the true value of everything the company/ agency does. Support of the Czech Science Foundation GAČR 18-01246S is gratefully acknowledged

3 - Interval eigenproblem in max-Lukasiewicz algebra
Zuzana Nemcova, Martin Gavalec

Max-Lukasiewicz fuzzy algebra can be used for description of the states of discrete-event systems. Steady states of such systems correspond to the eigenvectors of given matrices. Investigation the eigenproblem solution is thus very important for applications. In the real world, the values of specific parameters describing some system or situation (for example, resource consumption, time spent on the road, manufacture time) can very often lie in some interval rather than to be a single value. Considering lower and upper bounds for the entries of matrices and vectors gives us a possibility to describe the system more accurately, study the system model more corresponding with reality. The contribution describes the solution to the interval eigenproblem in max-Lukasiewicz algebra. It means, that for given lambda and interval matrix we are trying to find an interval vector solving the eigenproblem. Support of the Czech Science Foundation GAČR 18-01246S is gratefully acknowledged.

4 - EA-eigenvectors of interval fuzzy matrices
Martin Gavalec, Ján Plavka

In fuzzy algebra, the classical addition (multiplication) of real numbers are replaced by binary operations maximum (minimum). The matrix operations for fuzzy matrices and vectors are defined analogously. A vector x is said to be an eigenvector of matrix A, if the fuzzy product of A and x is equal to x.

The investigation of fuzzy eigenvector properties is important for the applications of stable fuzzy discrete dynamic systems. The values of vector (matrix) inputs in practice are usually not exact numbers and they can be considered as values in some intervals. Suppose that for every component in the considered vector x (or matrix A), the value interval is associated with the existential or with the universal quantifier. Then we assume that the components associated with existential (universal) quantifier must admit at least one value (all values) in the corresponding interval of values.

Thus we can split the interval entries of matrix and vector according to those containing universally quantified entries and to those containing existentially quantified entries. In this paper the properties of interval eigenvectors with interval coefficients dependent on quantifiers are studied. Illustrative examples are presented and efficient algorithms for checking the equivalent conditions are described.

Support of the Czech Science Foundation GAČR 18-01246S is gratefully acknowledged

■ MD-45
Monday, 14:30-16:00 - Q117

TSP and VRP variants

Stream: Transportation and Logistics
Invited session
Chair: Federico Trigos

1 - Modelling efficient routing in a dynamic network: a synergy of time dependent TSP and single machine scheduling problem
Alaleh Maskooki, Yury Nikulin

The paper addresses a variant of the travelling salesman problem. Assume a dynamic network of n nodes, where the locations of nodes change during the time. The moving nodes can appear in the area of measurement in different times, move along a random route and exit the area after a while. The question is how to travel among these moving targets, such that we visit as many nodes as we can, with the shortest possible distance. The above-mentioned optimization problem is raised from a real logistic service problem for optimizing the navigation of a service boat, which can be considered as an extension of the time-dependent travelling salesman problem. In this paper, a bi-objective integer linear programming model for routing and scheduling in a dynamic network is presented, and a heuristic algorithm for time splitting is proposed to improve the efficiency of the model on large-size datasets. The performance of the introduced algorithm is evaluated on real data, in which the geographic coordinates of vessels during a 16-hour interval are recorded for three days. The results of this research can be used in various logistic applications, specifically maritime management services.

2 - About the performance of the Traveling Salesperson Problem hyper-spherical based heuristic over non symmetric instances
Federico Trigos, Aydin Nassehi

The TSP hyper-spherical-based heuristics introduced a novel interpretation of the geometry of the TSP feasible region by showing that all TSP feasible solutions are contained and connected over the surface of the convex hull of an hyper-sphere. The heuristic starts at a feasible solution and moves through feasible solutions taking advantage of this new interpretation of the feasible region. The construction of this heuristic is highly compatible for parallel computing implementations and has being deployed on the parallel architecture of a commercially available graphical processing unit (GPU). Numerical experimentation over well know TSP non symmetric instances show that both the heuristic and the implementation are efficient.

3 - Dynamic Time Window Reassignment
Kevin Dalmeijer, Remy Spliet, Albert Wagelmans

We propose to improve customer satisfaction in delivery networks by dynamically reassigning time windows. Specifically, we consider delivering goods to customers within given time windows, and we improve customer satisfaction by giving the distributor the possibility to dynamically reassign the time windows of the customers when faced with uncertainty. Time window reassignment in itself is not appreciated by the customer. However, being informed timely that a delivery will be made in a later time window is preferred to not being informed at all. To the best of our knowledge, dynamically reassigning time windows to improve customer satisfaction has not been considered in the literature. We assume that travel times and service times are stochastic, and that their value only becomes known after serving a customer or traveling an arc, respectively. This setting is relevant for, e.g., parcel delivery and repairmen scheduling. We first consider the case where the route is fixed and we have to decide when to reassign which time window, and how much the time window is moved. We model customer satisfaction and we provide exact and heuristic methods for reassigning time windows to maximize satisfaction. Next, we explore integrating customer satisfaction into the routing phase. We present results comparing the optimal time window reassignment to multiple heuristics that are inspired by practice. Finally, we analyze the effect of including customer satisfaction in the routing phase.

■ MD-46

Monday, 14:30-16:00 - L243

Generalized Nash Equilibrium and Applications

Stream: Variational analysis, games and intertwined optimization problems
Invited session
Chair: Giancarlo Bigi

1 - A Decomposition Method for Convex Generalized Nash Equilibrium Problems
Tangi Migot, Monica-Gabriela Cojocaru

Generalized Nash equilibrium problems (GNEP) are a potent modeling tool that have developed a lot in recent decades. Much of this development has centered around applying variational methods to the so-called GNSC, a subset of GNEP where each player has the same constraint set. One popular approach to solve the GNSC is to use the apparent separability of each player to build a decomposition method. This method has the benefit to be easily implementable and can be parallelized. Our aim in this talk is to show an extension of the decomposition methods to the GNEP, that is not necessarily with shared constraints.

2 - Numerical Methods for Equilibrium Selection in Generalized Nash Equilibrium Problems
Axel Dreves

Recently, a new solution concept for generalized Nash equilibrium problems was published. This concept selects a reasonable equilibrium out of the typically infinitely many. The idea is to model the process of finding a compromise between the players by solving parametrized generalized Nash equilibrium problems. This results, under suitable assumptions, in a unique solution path, whose limit is the selected equilibrium. In this talk, we discuss algorithmic realizations of the concept. First, we present a homotopy method that tries to follow the solution path, using semismooth Newton steps as corrector steps. We provide sufficient conditions for the convergence of the algorithm. Second, we consider the 2-player case, and introduce a discrete best-response approach, resulting in a Jacobi-type method. In this way we find a different motivation for the continuous equilibrium selection concept. We discuss convergence of the numerical scheme for some special cases of generalized Nash equilibrium problems with linear constraints and linear or quadratic cost functions.

3 - Generalized Nash equilibrium and online content diffusion
Laura Rosa Maria Scrimali

This paper develops a dynamic network model of competition for the diffusion of online contents in the case of coupled constraints. We consider a two-layer network consisting of content providers and viewers. Each content provider seeks to maximize the profit by determining views and quality levels. The problem is formulated as a Generalized Nash equilibrium model and, using the concept of variational equilibrium, is described by a variational inequality. We then construct the projected dynamical systems model, which provides a continuous-time evolution of views and quality levels, and whose set of stationary points coincides with the set of solutions to the variational inequality.

■ MD-47

Monday, 14:30-16:00 - L247

Behavioural operations

Stream: Behavioural OR
Invited session
Chair: Ilkka Leppanen

1 - Can the sales-operations conflict reduce the bullwhip effect?
Murat Kaya, Gürdal Ertek, Özlem Çoban

Bullwhip effect refers to the phenomenon of increased order size variability as one moves upstream in a supply chain. In this study, we propose a modified version of the well-known beer game with two decision makers at each echelon who has conflicting incentives regarding the order quantity decision. The performance of one decision maker (the sales manager) is measured with the backlog cost; whereas, the performance of the other (the operations manager) is measured with the holding cost. Our beer game experiments with human participants show that the conflict in group decision making in the modified game can dampen the bullwhip effect relative to the standard game, in which there is only one decision maker at each echelon. Thus, the well-known conflict between the sales and operations functions of a firm may in fact be a value-creating dynamic for supply chains.

2 - Risk judgments in hurricane preparation decisions
Eva Regnier

Officials responsible for people and operations in hurricane-vulnerable regions must make high-stakes preparation decisions with incomplete information. The decision problem is dynamic with frequent forecast updates, multiple inter-related decisions, and forecast products that evolve from season to season. To help the Marine Forces, we developed a rich and realistic Hurricane Decision Simulator that lets users practice making these critical decisions and receive detailed operationally relevant feedback on implementation and storm- and decision-specific consequences. The simulator has improved training and understanding of forecast products in the Marine Forces Reserve in New Orleans.

We report on a new experimental simulated scenario that includes just a single decision—the user chooses whether and when to prepare—with exclusively financial impacts, designed to study the impact of use of the simulator on risk judgments.

3 - Role of gender-specific behaviour in supply contract decisions - An experimental investigation
Kumaravel Sivakumar

Purpose: In the extant literature on supply chain contracts, we observe that decision makers often deviate from the optimal order quantity decisions. Though certain behavioural explanations such as pull-to-center effect, demand chasing and other heuristics and biases are studied, the role of gender specific characteristics and behavioural differences has received scant attention. We aim to address this gap by an empirical study, involving an experimental investigation. Design/Methodology/Approach: We address our objective by designing and conducting an experimental study on the students of a B-school in India. Subjects take the role of a retailer who faces an uncertain demand for a perishable product, whose demand has to be estimated before the selling season (newsvendor setup). The experimental protocol consists of a behavioural assessment, followed by ordering decisions for revenue sharing and buyback contracts. The baseline experiment is followed by an intervention to improve the decision, viz. motivate subjects to move towards the optimal quantity. Originality/Value: This study aims to inform the existing body of knowledge on supply chain contracts, on how gender specific behavioural characteristics/personality traits of an individual affect order quantity decisions. Research Implications: The study would be valuable to contract designers to model contract parameters, keeping in mind the behavioural characteristics and thereby achieve supply chain coordination.

■ MD-48

Monday, 14:30-16:00 - L248

Biomathematical and Health modeling II

Stream: Applications of Dynamical Models
Invited session
Chair: Brian Reddy

1 - Dynamic Prioritized Home Healthcare Scheduling and Routing Problem
Ahmet Cinar, Sibel Salman

A Turkish company that sells prescribed medical nutrition products provides follow up services to its patients that are fed by tube or orally. Each nurse visits a set of patients for whom she is responsible at home. Currently, the managers cannot control whether the nurses visit the right patients in the right order and how they handle the dynamic arrival of emergent urgent patients during the day. We define an optimization framework to increase the effectiveness and efficiency of the visits during the entire planning horizon. At the beginning of the planning horizon, an Adaptive Large Neighborhood Search (ALNS) algorithm runs to determine which patients to visit on each day of a multi-period planning horizon and in which order to visit them to maximize the total priority of visited patients and to minimize the total routing time. Then, on each day some emergent patients with urgent conditions arrive dynamically. The emergencies are accumulated until predetermined re-optimization times. When a re-optimization time comes, the current plan is re-optimized with the accumulated new arrivals by a mixed-integer programming model (MIP). Solutions generated with respect to different processing rules for new arrivals are evaluated with respect to several performance measures, including the waiting time of urgent patients and the number of patients whose visit times are delayed.

2 - Optimizing Appointment Strategies for Outpatients at Irish Hospitals
Helmut Simonis, Barry OSullivan

Optimizing Appointment Strategies for Outpatients at Irish Hospitals

Helmut Simonis, Barry O'Sullivan

Waiting times for patients in Irish hospitals have grown in recent years to unprecedented levels, at the end of 2018 there were 520,000 people waiting to see a specialist for an outpatient appointment, out of a total population of 4.77 million in Ireland. We investigate the use of data analytics and optimization to understand the current situation, predict future short and medium term demand, and study the impact of changes in processes and resource levels. While overall resource levels are clearly inadequate, we also study the impact of did-not-attend no-shows, the possibility of overbooking, and of load distribution across clinics and hospitals. One of the challenges in improving waiting times is due to the different needs of routine and urgent patients. We have to issue appointments for routine patients before the demand of urgent patients is known. If we reserve too much capacity for urgent patients, there will be unused slots that are difficult to use effectively if not required. Current practice can lead to very imbalanced waiting times for patients in the same cohort, while an optimized appointment strategy reduces both maximum wait-times and the variance within patient groups across specialities, hospitals and regions.

3 - The Nurse-Patient Assignment Problem Focusing on Quality of Care
Ruonan Zhang

In this work we consider assigning nurses to patients to perform home health care services. Different from the models that aim to help nurse management, for example, minimizing travel distances and balancing workload, we take patients' perspectives and focus on improving the quality of care. Two metrics that measure the quality of care are derived: one addresses the continuity of care and the other considers the urgency level updates. We propose two mixed integer programming models to solve the multi-period nurse-patient assignment problem and present several insights obtained by analyzing the computational results.

4 - Explaining county-level spatial accessibility to good nursing home care in the US, using socio-demographic and economic factors.
Brian Reddy, Stephen ONeill, Ciaran ONeill

Spatial accessibility to medical services requires the consideration of 1) the number of providers available, 2) their capacity and 3) the distance/time required to access them. For nursing homes, spatial accessibility is particularly important because location is the most frequently cited factor for patients in their choice of a home. For two timepoints, 2011 and 2016, we derived the geolocations of circa 15,000 nursing homes in the contiguous US using Centers for Medicare and Medicaid Services (CMS) "COMPARE" datasets, and match these homes' locations to circa 450 variables from county-level American Community Survey datasets. Spatial accessibility to nursing home care was calculated for all counties and subsequently mapped. The cumulative distance to "good" homes, the number of beds in each home and the county's population aged over 65 were accounted for in the accessibility measure. In general, the Midwest was found to have the highest accessibility levels, and the Southwest the lowest. Using random forest, CART and LASSO approaches, the importance of specific county-level demographic and economic factors in determining accessibility was investigated. At both time points, counties with high levels of Native Americans in particular were found to have poorer access, in addition to several other recurring factors. The findings imply that extra efforts may be required to address inequalities and to ensure all communities have good access to nursing home care.

■ MD-49

Monday, 14:30-16:00 - L249

Software for optimization model building

Stream: Software for Optimization
Invited session
Chair: Susanne Heipcke

1 - Lamodal: A web application for collaborative development of mathematical models in AMPL
Davi Doro, Ricardo Camargo

Lamodal is a web application developed to facilitate the collaboration between members of a mathematical optimization team. It is easy to use and everything cloud-based: no need for local execution of solvers. This is possible thanks to NEOS-server, a free internet-based service for solving numerical optimization problems. This remote solver service, combined with project management and collaborative editing features, makes Lamodal a very useful application for small, medium and large teams.

2 - Optimization Modeling in MATLAB
Paul Kerr-Delworth, Aurele Turnes, Mary Fenelon

The problem-based workflow for optimization problems has made it much easier to model and solve such problems in MATLAB. First, optimization variables are identified and defined. Next, familiar MATLAB operators can be used to define the objective and constraints as expressions of the optimization variables. The optimization solver is then selected automatically based on the type of constraints and objective. Large and complex optimization models can be expressed compactly using MATLAB arrays to index optimization variables and expressions. An overview of the problem-based workflow will be presented and we will demonstrate new capabilities with examples.

3 - Mosel 5: next generation application design features for optimization projects
Susanne Heipcke

Important current trends influencing the development of modelling environments include expectations on interconnection between optimization and analytics tools, easy and secure deployment in a web-based, distributed setting and not least, the continuously increasing average and peak sizes of data instances and complexity of problems to be solved. In this talk we discuss how Mosel 5 builds out its functionality for supporting a dynamic and modular structure in the implementation of optimization projects, thus facilitating the collaboration of larger teams (typically covering different areas of expertise) in the development and maintenance of end-user applications. Relevant new features include the dynamic handling of packages and the introduction of the concept of namespaces, equally supported by enhancements to the development environment Xpress Workbench. Furthermore, considerable performance improvements in the handling of large-scale data have been achieved via new data structures that are presented by means of examples. Having turned Xpress Mosel into free software little over a year ago, an increasing number of contributions are accessible via Github: https://github.com/fico-xpress/mosel

4 - A multi-armed bandit based approach to operations workflow prioritization using nonstationary parametric Bayesian UCB
Max Buckley, Francisco Passos, Ivan Slijepcevic

Sequential experimental designs, and more specifically multi-armed bandit formulations, have proven their effectiveness in several business domains. By recasting the problem of operations workflow prioritization in a labour restricted environment as a multi-armed bandit problem, we can leverage well studied algorithms to optimize the key metrics of a business. In this paper, we demonstrate how the use of a nonstationary parametric Bayesian UCB (Upper Confidence Bound) algorithm can be used as a key part of creating a systematic approach to this problem. We introduce "Prioritization by Optimistic Impact", a new model for prioritization to the domain and explore some of the advantages of its use. We also briefly discuss how the model can be adjusted to deal with specific business requirements (Exploration / Exploitation focus) or other domain-specific preferences. Finally, we also explore how related methods like Thompson Sampling can be integrated to deal with delayed feedback as is often the case in queue-based workflows requiring human input.

■ MD-50

Monday, 14:30-16:00 - Mason Hayes & Curran

Pricing, advertising, and social learning

Stream: Operations/Marketing Interface
Invited session
Chair: *Xuying Zhao*
Chair: *Yao Zhang*

1 - Impacts of Supplier Enforced Cross-licensing in a Supply Chain
Tingliang Huang, Jingqi Wang

Qualcomm, the largest cellphone chipmaker in the world, was recently fined RMB 6.088 billion (approximately $975 million) by the Chinese government for alleged anti-competitive conducts including requiring downstream phone manufacturers to cross-license their patents to Qualcomm and its customers. Qualcomm's cross-licensing practice has also received similar charges or scrutiny in South Korea, Japan, European Union, and the United States. Motivated by this practice, we study the impacts of cross-licensing in a supply chain in which an upstream supplier requires its downstream competing manufacturers to cross-license. We find that, contrary to common belief, cross-licensing may incentivize more innovation investment by the weak manufacturer. In addition, besides the weak manufacturer, even the strong one may benefit from cross-licensing under certain conditions. However, the supplier does not always benefit from conducting the cross-licensing practice. We show that cross-licensing does not always hurt social welfare or consumer surplus as it is accused for. We also find that allowing manufacturers to charge each other royalties benefit manufacturers at the cost of the supplier and consumers. Our results shed light on how cross-licensing affects innovation, profits and welfare, which have managerial implications to firms in high-tech industries, as well as to policy makers around the world.

2 - Information Sharing and Product Quality in Online Markets with Social Learning
Dongwook Shin, Assaf Zeevi

This paper investigates the problem of information sharing in a supply chain, where a manufacturer sells a product through an online retailer. The online retailer has a private source of information about customer demand, which may or may not be shared with the manufacturer. Salient features of our problem are (a) the manufacturer can determine the quality of its product according to the information sharing arrangement with the retailer and (b) sales are affected by product reviews generated by buyers. Under a linear wholesale price contract, we show that the retailer may share information with the manufacturer if the information yields a sufficiently strong signal about customer demand. However, we show that review-based social learning makes it less attractive for the retailer to share information. Further, we find that information sharing improves the product's quality in online markets, but customers can be worse off due to the stronger effect of double marginalization.

3 - Feedback Stackelberg-Nash Equilibrium in a Mixed Leadership Game of Cooperative Advertising
Suresh Sethi, Alain Bensoussan, Anshuman Chutani

We characterize a feedback equilibrium of a general infinite-horizon Stackelberg-Nash differential game where the roles of the players are mixed. By mixed we mean that one player is a leader on some decisions and a follower on other decisions. We prove a verification theorem that reduces the task of finding equilibrium strategies in functional spaces to two simple steps: First solving two static Nash games at the Hamiltonian level in a nested version and then solving the associated system of Hamilton-Jacobi-Bellman equations. As an application, we study a novel manufacturer-retailer cooperative advertising game where, in addition to the traditional setup into which the manufacturer subsidizes the retailer's advertising effort, we also allow the reverse support from the retailer to the manufacturer. We find an equilibrium that can be expressed by a solution of a set of quartic algebraic equations. We then conduct an extensive numerical study to assess the impact of model parameters on the equilibrium.

4 - Pricing and Frills with Online Product Reviews
Yao Zhang

In this paper, we investigate the joint optimization of pricing and frill decisions for a competitive online retailing market. We develop four game-theoretic models for the constructed frill scenarios, respectively. By comparing the equilibrium decisions under the four scenarios, we determine the optimal product price and frill strategies. We find that: (1) Interestingly, compared with the low-reputation retailer, the high-reputation retailer prefers more to offer frills to improve its review ratings; (2) The low-reputation retailer may offer less frills compared with the competitor with higher reputation. Intuitively, a low-reputation retailer may offer more frills to improve its online reputation. However, from this result, retailers should not always spend more resources promoting inferior products in a competitive context; (3) High effectiveness of the offered frills will hurt the retailer with low reputation, and the retailer can gain higher profits when the effectiveness of the frills is low; (4) Better online reviews entailed by the offered frills will encourage retailers to raise their respective product prices; (5) From retailers' perspective, frills can increase their profits in some cases, however the frills will hurt social welfare. The managerial implication is that retailing platforms should prohibit the frill behaviors from online sellers.

■ MD-51

Monday, 14:30-16:00 - William Fry

Real Options: Applications

Stream: Optimal Control Theory and Applications
Invited session
Chair: *Sergio Vergalli*

1 - Multi-objective infrastructure investment under uncertainty
Maria Lavrutich, Verena Hagspiel

We study optimal infrastructure investment decisions of a social planner (SP) that has to anticipate capacity investment of a private company (PC) in a market characterized by uncertain demand. The proposed model captures the investment decisions of the SP and PC and accounts for the conflicting objectives and game-theoretic interactions of the distinct agents. Taking an option-based approach allows us to study the effect of uncertainty on the investment decisions, and to take the agents' discretion over investment timing as well as size into account. We show, if and how the SP can align the decision of the PC with the social optimum using the fact that the PC is dependent on the infrastructure provided.

2 - On the Value of the Option to Abandon a Construction Project of Uncertain Duration
Jacco Thijssen

We consider a new model of optimal investment in projects with stochastic time to build. Both revenues and construction progress are assumed to follow a continuous-time stochastic process. The model is an extension of Thijssen (2015, "A model for irreversible investment with construction and revenue uncertainty", emphJournal of Economic Dynamics and Control, textbf57, 250–266). Contrary to that model we add additional flexibility. First, the decision maker can postpone exploitation of the project once construction is finished. Secondly, the decision maker has the option to abandon construction before the project is finished. The latter source of flexibility leads to the analysis of a new, genuinely two-dimensional, constrained optimal stopping problem. We prove existence of a solution as well as several of its properties. We introduce a recursive finite difference algorithm to numerically solve this problem. We apply the model to the UK's planned high-speed rail line from London to Birmingham (HS2) and find that it does not currently represent value for money.

3 - Planned Obsolescence: a Dynamic Analysis
Richard Hartl, Peter M. Kort, Stefan Wrzaczek

We consider a firm that is producing a durable good. The disadvantage of a durable good that does not break down is that a consumer only needs to buy once. This in contrast with a durable good that breaks down often, because then every time the consumer has to decide whether to purchase this product again. If the consumer decides positively, the firm's revenue goes up. On the other hand, if a product breaks down too often, the consumer is more inclined to decide not to buy this product anymore. The above makes clear that when in the production process the firm decides about the quality of the product it faces the following trade off: a high quality implies a high reputation but a low breakdown probability so that consumers will not repurchase too often, whereas a low quality means that the product breaks down soon, implying that consumers need to buy this product again but at the same time this damages the product's reputation, which reduces demand. The paper investigates this problem in a dynamic model of the firm that explicitly takes account of the time the product is sold and the age of the product. First the optimal steady state problem (OSSP) is investigated and then the transient behavior is analyzed. We present several scenarios and obtain surprising results, e.g., that for high variance of the time to breakdown, an increase in the legal warranty period can make firms reduce the average time to breakdown.

4 - Photovoltaic Smart Grids in the prosumersinvestment decisions: a real option model
Sergio Vergalli, Marta Castellini

The last decades have been characterized by a growing attention and technological progress in the renewable energy sources' field. The worldwide recognition of a duly need of a sustainable development in productionhas in fact fostered the search for alternative energies respect to conventional ones.In this context there has been an increase in the number of distributed generation power plants both in Italy and in many EU countries. The new alternative sources have the advantage of a lower environmental impact but they are often characterized by a discontinuous production. Smart grids have the significant advantage of increasing the flexibility of production and consumption. Smart grids give producers and consumers the opportunity to be active in the market and to strategically decide their optimal production/consumption scheme. Our paper provides a theoretical framework for modeling the decision to invest of two agents to invest in two photovoltaic plants, assuming they are integrated into an intelligent network. To capture the value of managerial flexibility, a real option approach is implemented. The purpose of the paper is to verify if the energy exchange between agents is convenient. Secondly, we will try to calculate the optimal size of the plant in order to maximize the benefit of each agent. Finally, the model will be calibrated and tested using energy market data.

Monday, 16:30-17:30

■ ME-01

Monday, 16:30-17:30 - O'Reilly Hall

Ulrike Reisach

Stream: Plenaries
Plenary session
Chair: *Seán McGarraghy*

1 - Artificial Intelligence - How Ethics and Governance Could Contain the Manipulation of Societies
Ulrike Reisach

Artificial Intelligence (AI) in this plenary comprises machine learning systems for tracking, profiling, forecasting and making recommendations. Due to their ability to learn and evolve dynamically, they are much faster and more powerful than previous digital tools. This can facilitate both intended and unintended outcomes. It particularly applies to search engines and social media, where a broad public is addressed and where bots can multiply the effects. For example, the Brexit referendum, and the presidential elections in the USA and Brazil, have started a discussion about whether and how machine learning techniques could influence citizens' decisions. The potential impact of machine learning algorithms on the choices and opinions of users of search engines and online media, within and across borders, is discussed in this plenary. Endogenous and exogenous factors, which have the potential to influence the process, quality and outcomes of decision making are explained. Examples will show how organizations and their designers, architects and developers, can ensure compliance with ethical and social norms, and create trust in their systems among users and other stakeholders who might be directly or indirectly affected. Ethics codes and governance approaches will be discussed, as well as their perception and effectiveness in cyber systems, within the political frameworks of the EU, the USA and China. The plenary concludes by exhorting the operational research community to make the public more aware of the power of Artificial Intelligence, and how understanding it can help societies protect themselves from societal and political manipulation.

Monday, 17:45-19:00

■ MF-01

Monday, 17:45-19:00 - O'Reilly Hall

Women in OR - The Equality, Diversity and Inclusion Agenda: How do we weigh a Tonne of Feathers?

Stream: Women in OR
Invited session
Chair: *Paula Carroll*

Tuesday, 8:30-10:00

■ TA-01

Tuesday, 8:30-10:00 - O'Reilly Hall

Anna Nagurney

Stream: Tutorials
Tutorial session
Chair: *Matthias Ehrgott*

1 - Game Theory and Variational Inequalities: From Transportation and Supply Chains to Financial Networks and the Internet
Anna Nagurney

In this tutorial I will present the fundamentals of the theory of variational inequalities with a focus on game theory and numerous network-based topical applications, beginning with congested urban transportation networks, which have served as the foundation for many methodological advances. Multitiered supply chain networks with applications as varied as blood supply chains in healthcare to fresh produce supply chains and disaster relief supply chains will also be highlighted. I will then proceed to discuss financial networks, draw analogies to other network systems, including the Internet, and demonstrate how they are also the subject of numerous cyberattacks. Recent results from game theory and variational inequalities will be covered in the setting of cybersecurity investments and vulnerability analysis to contrast and compare noncooperation versus cooperation in major industries, notably, in retail and in financial services.

The audience will learn about variational inequality theory as a powerful tool for the modeling, analysis, and computation of solutions to a breadth and depth of applications in which there are multiple interacting decision-makers.

■ TA-02

Tuesday, 8:30-10:00 - Moore Auditorium

EEPA 1

Stream: EURO Excellence in Practice Award
Award Competition session
Chair: *Erik Demeulemeester*

1 - School Choice in Chile
Natalie Epstein, José Correa, Rafael Epstein, Juan Escobar, Ignacio Rios, Bastián Bahamondes, Carlos Bonet, Nicolás Aramayo, Martin Castillo, Andres Cristi, Boris Epstein

Centralized school admission mechanisms are an attractive way for improving social welfare and fairness in large educational systems. In this paper we report the design and implementation of the newly established school choice mechanism in Chile, where over 274,000 students applied to more than 6,400 schools.

The Chilean system presents unprecedented design challenges that make it unique. On the one hand, it is a simultaneous nationwide system, making it one of the largest school admission problems worldwide. On the other hand, the system runs at all school levels, from Pre-K to 12th grade, raising at least two issues of outmost importance; namely, the system needs to guarantee their current seat to students applying for a school change, and the system has to favor the assignment of siblings to the same school.

As in other systems around the world, we develop a model based on the celebrated Deferred Acceptance algorithm. The algorithm deals not only with the aforementioned issues, but also with further practical features such as soft-bounds and overlapping types. In this context we analyze new stability definitions, present the results of its implementation and conduct simulations showing the benefits of the innovations of the implemented system.

2 - Optimal Scheduling of Field Resources for Power Plant Outages
Rajeev Namboothiri, Srinivas Bollapragada, Babu Narayanan, Guillaume Camard, Ahmed Khattab

GE Power installs and supports power generation equipment around the world. These power plants undergo periodic planned outages and forced unplanned outages to ensure safe and efficient operations. These outages require mobile field resources with specific skillset for a specific duration to perform maintenance tasks. A host of additional constraints restrict the eligibility and availability of a field resource to perform a maintenance task. GE Power Middle East Africa (MEA) centrally manages the deployment of field resources to power plant outages in more than 25 countries across MEA. We developed a Field Resource Optimizer product to provide resource scheduling recommendations to minimize the total cost associated with field service operations while meeting all the real-world constraints associated with assigning field resources to outage tasks. The standard formulation of the field resource allocation problem results in a mixed integer linear program that is too large to be solved in a reasonable amount of time for practical use. Using constraint programming techniques and intelligently designing the cost function, we reduced the size of our math programming formulation. The resulting math program, though much smaller in size, was still not practical for implementation. We therefore developed a novel solution procedure that iteratively solves a series of linear programs to achieve the optimal solution within a few minutes. GE Power has been using this tool in the MEA region since June 2016, resulting in operational cost savings of tens of millions of dollars.

3 - Operations Research Improves Biomanufacturing Efficiency at Merck Sharp & Dohme
Tugce Martagan, Yesim Koca, Ivo Adan, Bram van Ravenstein, Marc Baaijens, Oscar Repping

Biomanufacturing methods use live systems (e.g., bacteria, mammalian or insect cells) to manufacture the desired therapeutics. The use of live systems leads to several challenges, including batch-to-batch variability and uncertainty in the production yield and quality. In order to address these challenges, a multidisciplinary team of researchers from Merck Sharp and Dohme (MSD) Animal Health and Eindhoven University of Technology collaborated over three years and developed a portfolio of decision support tools. These tools consist of stochastic optimization and simulation models to reduce biomanufacturing costs and lead times. More specifically, the project builds a data-driven framework that can effectively integrate the business risks and process trade-offs along with the constraints posed by the biological and chemical features of the underlying processes. MSD Animal Health has successfully implemented and used these tools in daily practice, and achieved an average of 40% improvement in production yield (per batch) leading to an additional output in sales increase of EUR 50 million per year. In addition, the project provided an improved use of historical production data and enabled a rigorous assessment of the operating policies and business risks.

■ TA-03

Tuesday, 8:30-10:00 - Q106

OR impact across industries

Stream: Practice of OR (Making an Impact)
Award Competition session
Chair: *Jean André*
Chair: *Antti Punkka*

1 - Airport Ground Staff Scheduling: A Real-World Business Application
Peter Fusek, Andreas Klinkert

Staff scheduling and rostering involves a number of hierarchical subproblems including demand modeling, task generation, shift design, days-off scheduling, shift assignment and real-time dispatching. When solving highly constrained large-scale workforce planning problems it is usually not computationally practical to deal simultaneously with all these tasks. Real-world software solutions typically decompose the overall planning task into heuristically designed subproblems which then are tackled by a variety of suitable exact and heuristic methods. We present results from a major research and business project with Swissport International, the largest ground handling company worldwide, which provides services for 850 customers and 265 million passengers a year, with a workforce of 68 000 personnel at 315 airports. During a long-term strategic cooperation, a high-performance software for automated staff scheduling has been developed, which is able to solve the complex large-scale rostering problems in Swissport's airport operations. The methodology comprises a broad range of optimization techniques including preprocessing, decomposition and relaxation approaches, mixed-integer programming models, and various heuristic procedures. Operational deployment started at Zurich Airport and is continually being extended to other airports and customers. Bottom line benefits include faster and more robust planning processes, improved roster quality, and substantial financial savings.

2 - Examples on mathematical decision support models for operations management and planning
Antti Punkka

We present examples on how development of mathematical decision support models and their implementations have improved operations management and planning in the Finnish state-owned railway operator VR. Our examples' application domains include personnel planning, locomotive allocation, and maintenance scheduling. The developed solutions utilize, for example, mixed integer linear optimization, constraint programming, combinations of heuristic solution algorithms, and Monte Carlo simulation.

■ TA-04
Tuesday, 8:30-10:00 - Q116

Teaching OR/MS 1

Stream: OR Education
Award Competition session
Chair: Beatriz Brito Oliveira

1 - Business game for teaching planning methods in logistics and production
Alexander Hübl

A business game for teaching planning methods in logistics and production planning for educational purpose has been designed. Optimal adjusted planning systems reduce the waste of resources. Android based tablets are connected to the simulation model and allow the gamers to control the machines (start and stop production). Therefore, a server is installed, which is responsible for the connection of the tablets with the simulation model itself. Based on the selected planning method (MRP, Conwip, Kanban, Reorder policy) production orders are released and displayed at the tablet.

A defined process with five machines in sequence producing three different types of sellable products is configured. Utilization, production lead-time, work in process, finished goods inventory and service level are the performance indicators in this game. Based on those performance indicators the gamers have to improve the system by changing the planning parameters (MRP: lot size policy, planned lead times, safety stock; Conwip: work ahead window, Wipcap; Kanban: Kanban size, number of Kanbans; Reorder policy: reorder point, lot size).

2 - Experiential Learning Opportunities through Applications in Healthcare Scheduling
Amy Cohn

Much of my research is focused on developing, implementing, and applying Operations Research-based decision support tools to solve complex, multi-criteria optimization problems in healthcare. Specifically, I solve personnel scheduling problems such as the assignment of residents to training rotations or attending physicians to clinical unit. This applied research has also presented me with the opportunity to provide experiential learning opportunities to a large number of undegraduates and masters students. They not only learn to address the technical challenges of a complex combinatorial optimization problem, but gain training in multi-disciplinary team work, in problem scoping, in communicating across different fields, and in tackling the practical challenges of implementing a theoretical solution in real-world practice. I will present my experience in working with a large and diverse group of students in such a learning environment and share lessons learned along the way.

3 - Teaching OR for public policy
Ine Steenmans

In an age of accelerated access to data, changing demands for participatory processes, and often increasingly constrained resource contexts, the practical realities of policy work are changing rapidly. Senior officials need not only core skills such as project management, diplomacy and communication, but also strong foundations of analytic competency (OECD 2017). The education of future policy leaders is therefore shifting locus from focusing on a few analytic methods, such as descriptive statistics and survey design, to nurturing a broader literacy in skill areas as wide-ranging as decision analysis, evidence synthesis, data science, strategy and user centric design. While typically absent from global public policy curricula, there is an increasing interest in integrating educational programmes with Operational Research content.

This paper presents the lessons learnt to date from two years of experience indesigning and delivering producing an OR curriculum for a Masters of Public Administration programme at the University College London. The curriculum blends soft OR methods such as goal modelling, morphological analysis and scenario analysis with 'hard' OR such as data science, predictive analytics, and optimisation. It concludes with reflection on the critical requirements for experiential pedagogy in meaningfully delivering the blended learning outcomes of such a programme.

4 - "IO Hackathon": a case study competition as an introduction to applied research in OR
Beatriz Brito Oliveira, Maria Antónia Carravilla, José Fernando Oliveira

"IO Hackathon" was an OR case study competition that took place in December 2018 in the Faculty of Engineering of the University of Porto, involving students who were enrolled in master-level OR classes in that term. The main goal of this pedagogic initiative was to foster a deep learning of critical OR concepts and skills, namely structuring and modelling complex problems, solving the models, analysing the solutions and drawing managerial insights from them. At the same time, it allowed students to have direct contact with a complex, real-world situation (contrasting with the usually structured textbook problems), thus challenging and broadening their OR skills and introducing them to first steps of applied research in OR. In this presentation, we aim to describe the objectives and structure of this pedagogic initiative and provide an account of the event, discussing feedback from the professors and students involved. Moreover, we will share the main results and discuss the main advantages and challenges of this activity.

■ TA-05

Tuesday, 8:30-10:00 - A003

Optimizing Sustainable Practices

Stream: OR for Sustainable Development
Invited session
Chair: *Sadia Samar Ali*
Chair: *Vida Maliene*
Chair: *Tatjana Vilutienė*
Chair: *Gerhard-Wilhelm Weber*

1 - Integrating the multiple criteria analysis and Building Information Modeling (BIM) to optimize the selection of sustainable building elements
Tatjana Vilutienė, Arvydas Kiaulakis

The variety of structural elements and availability of sustainable materials, different preferences of clients, architects, and structural designers make the decision-making process difficult in terms of sustainable solutions. Thus, the decision-making process requires applying additional techniques in order to optimize the assessment of many alternatives. Building Information Modelling (BIM) offers the possibility to assess different design alternatives at the conceptual stage of a project. BIM also help structural designers more easily select the right type of materials during the early design stage. With help of integrated tools, structural designers can assess the environmental impacts throughout the building's life cycle. Multiple criteria decision aiding methods give the possibility to improve the selection process. The proposed approach for sustainability analysis integrates the analysis of environmental, technological and economic factors, and application of Building Information Modelling (BIM) and MCDA methods.

2 - The Application of Multiple Criteria Decision Making Methods for an Assessment of High Street Sustainability
Vida Maliene, Isabel Atkinson, Steven Fowles

The decline of high streets in British towns due to external factors such as changing consumer trends, the growth of alternative forms of retail, changing economic conditions etc. is a topic which has received a great deal of political and media attention during the last decade. The performance of high streets is influenced by a multitude of complex and conflicting economic, environmental and social factors. However, despite this, existing performance measures continue to place emphasis on the retailing and economic functions of high streets. As consumer needs and expectations shift towards a preference for social and experiential high street features, the need to change the perception of high street success is increasingly important. The undertaken research contributes new and original knowledge through the development and validation of a complex model for the assessment of high street sustainability. The model comprises an all-inclusive set of criteria which reflects a high street's economic, environmental and social functions. The Multiple Criteria Decision Making (MCDM) methods: WSM, WPM, AHP, TOPSIS, COPRAS are innovatively applied to the assessment of high street sustainability, enabling a range of criteria which influence high street sustainability - including maximising (positive), minimising (negative), quantitative and qualitative criteria - to be incorporated into the model. The model is validated through a practical example of eight British town centres.

3 - Optimal allocation of defibrillator drones in mountainous regions
Christian Wankmüller, Christian Truden, Christopher Korzen, Philipp Hungerländer, Ewald Kolesnik, Gerald Reiner

Responding to emergencies in mountainous regions is quite challenging as air ambulances and mountain rescue services are often confronted with logistics challenges and adverse weather conditions that extend the response times to reach the patients' site. Sudden cardiac arrest (SCA) is the most time-critical event that requires fast medical treatment including cardiopulmonary resuscitation (CPR) and electric shocks by automated external defibrillators (AED). An emerging technology called unmanned aerial vehicles (or drones) allows overcoming the time criticality of these emergencies by reducing the time between SCA and early defibrillation. An AED equipped drone can departure from a base station and fly to the patients' location where a bystander receive it and start adequate interventions by using the AED. The subsequent paper considers this response system and proposes an integer linear program (ILP) to determine the optimal allocation of drone base stations in a given geographical region. The developed model follows the objectives to minimize the number of used drones and to minimize the average response times to SCA events. In an example of application, under consideration of empirical data, the authors test the developed model and demonstrate the capability of drones to fasten the delivery of AEDs to SCA patients. Results indicate that time spans between SCA and early defibrillation can be significantly reduced by the optimal allocation of drone base stations.

■ TA-06

Tuesday, 8:30-10:00 - A004

Economics of energy markets

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: *Christoph Weber*
Chair: *Michael Bucksteeg*

1 - Structural Regulatory Uncertainty in Electricity Markets
Jonas Egerer

The project investigates uncertainty regarding the implementation of price zones and its impact on investment incentives in generation and transmission capacity. It can be shown that even a small probability for the introduction of price zones can alter investment decisions, both with regard to transmission and generation capacity investments. Uncertainty not only affects regional distribution, but also the technology mix.

2 - Impact of topology control on zonal electricity market operations
Quentin Lété

We present a two-stage model of zonal electricity markets and we investigate the impact of topology control on the operations. We show preliminary results on illustrative examples.

3 - Prices in power system models
Alexander Zerrahn, Wolf-Peter Schill

Researchers and policy advisors regularly rely on linear electricity system models to analyze potential future states of the power market ex-ante. Market prices, and market values, are one outcome of specific interest. They are derived as the dual variable, or shadow price, of the energy balance, that equates supply and demand. We scrutinize this economic interpretation based on a generic LP electricity system model. Specifically, we derive expressions for prices if different restrictions apply and provide the economic intuition by clarifying the role of peak prices, storage, and a range of relevant constraints on renewable or fossil energy use.

4 - Flow-based market coupling with integrated redispatch
Michael Bucksteeg

Given the target of a single European power market the integration of national power markets is subject to ongoing further development. The last major step towards the target model was the introduction of the so-called Flow Based Market Coupling (FBMC) in Central Western Europe (CWE) back in 2015. However, at the political level there is criticism that TSOs reduce commercial capacities in favour of reducing internal bottlenecks and lowering redispatching costs. So far TSOs refrain from using costly remedial actions, i.e. redispatching measures, to increase the capacity domain given to the market. Against this background, we extend the FBMC approach by considering costly remedial actions during the capacity allocation stage and study the impacts on the capacity domain and market results.

■ TA-07

Tuesday, 8:30-10:00 - A007

OR in Agriculture and Forestry

Stream: OR in Agriculture and Forestry
Invited session
Chair: *Concepción Maroto*

1 - Multi-objective modelling approach for supporting fresh fruit harvest planning decisions
Marcela C. Gonzalez-Araya, Javier Gomez-Lagos, Wladimir E. Soto-Silva

One important stage of the fruit supply chain (FSC) is the harvest. This stage is seasonal and presents high variability in fruit yield and quality. During the season, farmers or orchard managers need to plan labor quantity, raw materials required, machinery, among others, according to a harvest calendar estimated by the agricultural engineers. This task is complex because every fruit and variety has a different ripening curve and the orchards usually have many fields with different kinds of fruit and varieties. Currently, in many countries, the harvest planning decisions are taken mainly based on the experience of the farmers or orchard managers, leading to discoordination of the FSC and fruit waste during this stage. For this reason, decision-support tools are necessary in order to facilitate the decision-making process and add flexibility for unexpected changes during the harvest season. According to this, in this study we propose a the multi-objective model for planning tactical decisions for one orchard in order to establish harvesting times for each fruit variety and associated resources (workers, machinery, raw materials, among others) for optimizing fruit quality and seeking to reduce the harvest calendar. We use the proposed model to solve different size instances using exact methods, aiming to verify the if the objective functions and defined constraints are coherent with the conditions observed for the real cases.

2 - Optimal crop selection and water allocation using dynamic crop models
Raphael Linker

We propose a general model-based optimization framework for selecting crops and/or allocating irrigation water. The main novelty of the approach is that it does not rely on predefined water productivity functions but rather the water productivity function of each crop at each location (i.e. for each soil) is estimated within the procedure itself by solving a separate multi-objective optimization problem (yield vs. seasonal irrigation). This step relies on well-established crop-soil-atmosphere dynamic models such as AquaCrop, DSSAT or SWAP. After computing all the relevant water productivity functions, optimal crop selection and/or water allocation is obtained by solving a single-objective (profit) optimization problem formulated using these water productivity functions. Before the start of the growing season, the proposed formulation enables solving simultaneously the problem of crop selection (or land allocation), i.e. which crops should be planted where, and water allocation, i.e. how much water should be provided to each crop, using historical weather data. During the growing period, the same formulation can be used to re-optimize periodically water allocation, taking into account the actual weather and the irrigation implemented so far, as well as changes in factors such as water quotas or crop value. The proposed framework is illustrated for a hypothetical farm consisting of two crops and three soils.

3 - Making the forest out of trees
Jussi Rasinmäki, Tero Heinonen

New inventory technologies, like very dense photogrammetric point clouds from drone flights, enable measuring the species, size and exact location of all the trees in a forest. This changes the forest management planning paradigm, as instead of basing the planning on areal inventory units for which mean tree characteristics have been measured, the starting point is a set of trees with attributes describing each of them. Aggregation of the trees in to management units is, however, necessary as the management decisions are not made tree by tree, but rather on contiguous areas that are homogeneous with regards to the tree stock composition. We present a case from Finland where for a set of forest estates, together covering roughly 3,000 ha, were mapped tree by tree using drones, and forest management plans were composed. The planning steps were (i) tree height and species based segmentation, (ii) forest growth simulation combined with spatial optimisation to maximise the net present value of the forest estate and the "operational quality" of the management units, and (iii) merging segments that were not included in the optimisation solution based on the current standing stock characteristics.

4 - Decision support systems for livestock production based on sustainable diets
Concepción Maroto, Marina Segura, Concepción Ginestar, Baldomero Segura

For decades linear programming has provided a powerful approach to calculate diets used in livestock production. Together with other advances in animal production, minimising the cost of feed has had a relevant impact on providing affordable meat from intensive pig and poultry farms. Nevertheless, there is an increasing worry of people about greenhouse gases and pollutant emissions due to food production. Therefore, sustainable meat production is a share responsibility for all stakeholders involved in supply chain management from farms to consumers. This paper proposes a decision support system based on goal programming as an approach to balance the economics and environmental criteria in order to provide diets that satisfy the animal requirements, minimise both the cost and environmental impact. Finally, an application to the European poultry sector will be presented.

■ TA-08

Tuesday, 8:30-10:00 - A008

Analytical Approaches for Humanitarian Risk and Needs Assessment

Stream: OR in Humanitarian Applications
Invited session
Chair: *Burcu Balcik*
Chair: *Melih Celik*

1 - Improving Information Accuracy and Precision in Post-Disaster Needs Assessment Routing
Melih Celik, Duygu Pamukcu, Burcu Balcik

Obtaining reliable information in post-disaster needs assessment depends on how much time is spent for sampling to collect information and how many different beneficiary groups are visited. Estimated information on the needs is an input for subsequent relief distribution, so accuracy and precision of the estimation directly effects the efficiency of relief operations. Since the total time to visit affected sites and to collect information from each site is limited, an efficient routing scheme is important to perform effective needs assessment.

In this study, we consider the problem of routing a needs assessment team in the aftermath of a disaster, where the decisions of which sites to visit, in what sequence to perform these visits, and how much time to spend to collect information in each site are made, subject to a total needs assessment time constraint. We formulate a mixed integer program and propose a tabu search heuristic to obtain near-optimal solutions. Our solution approaches are tested on randomly generated instances and a case study based on the 2011 Van Earthquake in Turkey.

2 - Disaster preparedness using risk-assessment methods from earthquake engineering
Maria Battarra, Burcu Balcik, Huifu Xu

Analysing the uncertainties associated with disaster occurrences is critical to make effective disaster preparedness plans. In this study, we focus on pre-positioning emergency supplies for earthquake preparedness. We present a new method to compute earthquake likelihood and the number of the affected people. Our approach utilizes forecasting methods from the earthquake engineering literature, and avoids using probabilistic scenarios to represent the uncertainties related to earthquake occurrences. We validate the proposed technique by using historical earthquake data from Turkey, a country under significant earthquake risk. We also present a case study that illustrates the implementation of our method to solve the inventory allocation problem of the Turkish Red Crescent.

3 - Evaluation of rapid needs assessment strategies in an uncertain and dynamic post-disaster environment
Mehdi Hakimifar, Burcu Balcik, Tina Wakolbinger, Christian Fikar, Vera Hemmelmayr

The rapid needs assessment process is carried out immediately after the onset of a disaster to investigate the impact of the disaster on the affected communities through field visits. The main objective of this study is to evaluate different strategies concerning site selection and routing decisions of the assessment teams while planning and executing the field visits. We present a simulation model, which enables us to incorporate various uncertain and dynamic aspects of the post-disaster environment. We evaluate different strategies based on real-world data from the 2011 Van earthquake in Turkey.

■ TA-09

Tuesday, 8:30-10:00 - B006

DEA theory and methodological developments

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Antonio Peyrache

1 - The Cost Metafrontier is Nonconvex in the Outputs since the Metafrontier is Nonconvex: The Price of a Convexification Strategy
Kristiaan Kerstens, Christopher O'Donnell, Ignace Van de Woestyne

Metatechnology frontiers have become a popular method to account for technological heterogeneity among producers. Though it is conceptually clear that the union of group frontiers normally results in a non-convex metaset, an overwhelming majority of authors seems to assume that a convexification strategy leads to an acceptable convex approximation of this non-convex metafrontier. However, Kerstens, O'Donnell and Van de Woestyne (2019) obtain new results on the union operator on technologies under various assumptions with regard to, e.g., returns to scale and convexity. These authors also empirically illustrate that such a convexification strategy is highly questionable. The purpose of this contribution is to transpose these results on the union operator from technologies to the cost function context: this is new to the literature. Furthermore, we explore to which extent such a convexification strategy -which seems almost unanimously pursued by most authors- is tenable when computing a cost function with respect to a metafrontier. We apply this methodology empirically on a secondary data set under the assumptions of constant and variable returns to scale. Anticipating our key results, we do establish a potential bias of the convexification strategy for the cost metafrontier.

2 - Defining cone extensions of nonparametric production technologies
Victor Podinovski

In data envelopment analysis (DEA), the cone, non-increasing and non-decreasing (NIRS and NDRS) extensions of production technologies are often used for the estimation of scale efficiency and characterization of returns to scale of decision making units. Such reference technologies are well-known for the conventional variable returns-to-scale model. However, for many other models, the construction of their cone, NIRS and NDRS technologies may be problematic. We present a general method of constructing such technologies for a very large class of polyhedral technologies. This class includes almost all known convex technologies used in DEA. Examples include technologies with multiple component processes, complex network structures, technologies that incorporate weight restrictions or bounds on the input and output values. We show how the cone, NIRS and NDRS technologies can be obtained from the statement of any polyhedral technology, in both the primal and dual specifications. This universal result effectively removes the need of bespoke development of the reference technologies for a growing number of production technologies suggested in the literature.

3 - Benchmarking: An approach for performance evaluation based on DEA
Inmaculada Sirvent, José L. Ruiz, Nuria Ramón

In management, organizations use benchmarking for the evaluation of performance in comparison to best practices of others within a peer group of firms in an industry or sector. An approach based on Data Envelopment Analysis (DEA) is proposed for the benchmarking of decision making units (DMUs) against several reference sets, which are selected from among those that span the facets of the efficient frontier. The evaluation against a wider spectrum of benchmarks provides a more comprehensive overview of units' performance within their environment than conventional DEA, which only considers one reference set (unit-specific) to that end. We refer to this approach as cross-benchmarking. Benchmarking models are developed which allow us to set the closest targets relative to the reference sets selected. The comparisons between actual performances and targets in the different scenarios associated with those reference sets may help identifying strengths and weaknesses. Linked to cross-benchmarking, we also show how to conduct a cross-efficiency evaluation in order to derive a ranking of units.

4 - Variable Selection in Data Envelopment Analysis
Antonio Peyrache, Christiern Rose, Gabriela Sicilia

The selection of inputs and outputs in data envelopment analysis (DEA) is regarded as an important step, that is normally conducted before the DEA model is implemented. In this paper, we introduce cardinality constraints directly into the DEA program in order to select the relevant inputs and outputs automatically, without any previous statistical analysis, heuristic decision making or expert judgement (though our method is not incompatible with these other approaches and indeed may help to choose among them). The selection of variables is obtained solving a mixed integer linear program (MILP) which specifies the maximal number of variables to be used. The computational time of the program is fast in all practical situations (with a sample size of 5,000 and around 100 variables to choose from, it solves in less than 10 seconds). We explore the performance of the method via Monte Carlo simulations. Some empirical applications are considered in order to illustrate the usefulness of the method.

■ TA-10

Tuesday, 8:30-10:00 - H0.12

Copositive and Quadratic Optimization

Stream: Copositive and Conic Optimization
Invited session
Chair: Paula Amaral

1 - Accelerated Proximal Gradient Methods for Quasistatic Analysis of Elastoplastic Continua

Yoshihiro Kanno

Recently, second-order cone programming (SOCP) and semidefinite programming (SDP) have attracted much attention in computational plasticity. This paper presents accelerated first-order methods for solving SOCP and SDP arising in the numerical analysis of elastoplastic continua. Elastoplastic body undergoes two types of deformation: Elastic deformation is reversible and plastic deformation is irreversible. The threshold separating these two deformations is called the yield criterion. When the inertial term in the equations of motion is negligible, deformation of a body is said to be quasistatic. It is known that the quasistatic elastoplastic problem with the von Mises yield criterion can be recast as SOCP, and the one with the Tresca yield criterion can be recast as SDP. Therefore, we can apply primal-dual interior-point methods with polynomial-time complexity to these problems. However, conversion of an incremental problem to the standard forms of SOCP or SDP requires many additional variables. In this paper, we propose to solve an equivalent problem in a form of unconstrained nonsmooth convex optimization. We develop an accelerated proximal gradient method for solving this form. Numerical experiments suggest that the proposed method outperforms a standard implementation of an interior-point method that solves the standard form of SOCP or SDP.

2 - Some efficiently solvable special cases of nonconvex QP

Michal Cerny, Miroslav Rada, Milan Hladik

We consider the class of quadratic programming problems with continuous variables and upper and lower bounds on variables (box constraints). In general, this formulation of the problem is known to be NP-hard. We discuss two special cases which can be solved by better algorithms than by the straightforward brute-force search. The first case involves quadratic programs where the objective quadratic form has low rank. If the rank is O(1), the method yields a polynomial-time algorithm. The second case involves quadratic programs where the objective quadratic form is of the form I - A, where A is a low-rank matrix.

3 - Linear Models for Complex Data Analysis

Paula Brito, Sónia Dias, Paula Amaral

In classical Statistics and Multivariate Data Analysis data is usually represented in a matrix where each row represents a statistical unit, or "individual", for which one single value is recorded for each numerical or categorical variable (in columns). This representation model is however too restricted when the data to be analysed comprises variability. That is the case when the entities under analysis are not single elements, but groups formed e.g. based on some given common properties, and the observed variability within each group should be taken into account. To this aim, new variable types have been introduced, whose realizations are not single real values or categories, but sets, intervals, or distributions over a given domain. Symbolic Data Analysis provides a framework for the representation and analysis of such complex data, taking into account their inherent variability. In this talk, we consider the case of aggregate numerical data described by empirical distributions, known as histogram data. Linear models for such distributional variables are proposed, which rely on the representation of histograms by the associated quantile functions. These then allow for linear regression, as well as for linear discriminant analysis for histogram-valued data. The identification of the corresponding models requires solving specific optimization problems. An application of the proposed methodology will be presented.

4 - Copositivity in fractional optimization

Paula Amaral, Immanuel Bomze

In this talk we will present some fractional problems involving quadratic functions and developed conic formulations for these hard optimization problems. The practical contribution is related with relaxations of these conic formulations that yield efficient lower bounds. From fractional quadratic functions in continuous and binary variables to continuous minimax fractional problems, the results were always encouraging and contribute to certify the well-known quality of bounds obtained from relaxations of copositive reformulations.

■ TA-11

Tuesday, 8:30-10:00 - H1.12

Applications of Nonlinear Programming

Stream: Nonlinear Programming. Theory and Methods
Invited session
Chair: Hector Ramirez

1 - Controlling recirculation rate for minimal-time bioremediation of natural water resources

Victor Riquelme, Alain Rapaport

We revisit the minimal time problem of in-situ decontamination of large water resources with a bioreactor, considering a recirculation flow rate in the resource as an additional control. This new problem has two manipulated inputs: the flow rate of the treatment in the bioreactor and the recirculation flow rate of the water resource between the pumping and reinjection locations. Although the velocity set of the dynamics is non-convex, we show that the optimal control is reached among non-relaxed controls. The optimal strategy consists of three sequential steps: 1. do not mix and take the flow rate of treatment that maximizes the concentration decay in the resource. 2. mix as much as possible and carry on with the flow rate that maximizes the concentration decay. 3. carry on mixing but do not treat the water. Finally, we show on numerical simulations that a significant gain in processing time can be achieved time when controlling in addition the recirculation flow rate.

2 - The continuous model for the open pit mine planning problem

Jorge Amaya, Emilio Molina, Cristopher Hermosilla

In this talk we analyze the mathematical framework for the open pit mine planning problem, based on continuous functional analysis. The traditional models for this problem have been constructed by using binary decision variables, giving rise to large-scale Mixed Integer Programming problems. Instead, in this talk, we introduce a continuous approach in a suitable functional space, essentially the real-valued functions that are Lipschitz continuous on a bounded two-dimensional region. We show existence results and investigate qualitative properties of the solutions, as for example, the behavior of the gain function along the border of the optimal profile of the pit, satisfying a slope and a maximum capacity conditions for extraction. We prove that the value distribution along the lower border of the optimal pit must be zero, when the slope or capacity constraint are not actives. This result comes from the tools provided by optimal control and calculus of variations. Finally, we use this characterization to propose a practical method for finding optimal profiles.

3 - Optimizing Free-flight Trajectories

Liana Amaya Moreno, Armin Fügenschuh

The rapid growth of air traffic in the recent years has put a lot of pressure on air traffic regulators to develop new practical approaches capable of coping with the demand and at the same time guaranteeing the safety of the operations. Free-flight Trajectory Planning is one of such approaches, where the full 4D space (3 spatial dimensions plus time) can, in principle, be used for planning the operations. This in turn allows for a better use of the space. The Free-flight trajectories presented in this work are computed by minimizing the fuel consumption an aircraft requires to carry out a specific flight. Therefore, the dynamic weather conditions of the portion of troposphere/stratosphere where the flight is to be planned need to be taken into account in order to avoid head-winds and benefit from tail-winds. Additional restrictions to the flight operation such as avoiding bad weather areas and respecting maximum diversion times are also considered for the computation of the trajectories. We present a mathematical formulation for the optimization of Free-flight trajectories by decomposing the problem in two separate phases, a horizontal phase and a vertical one. We formulate corresponding nonlinear models using AMPL and solve them using different nonlinear programming solvers. We present numerical results on several instances using real-world data.

4 - Nonlinear interior points methods in LocalSolver

Nikolas Stott

Interior points methods have first been introduced in the 1980s to solve linear programs. The key ingredient consists in moving the constraints into the objective, with a barrier penalization. Approximate optimal solutions are obtained quickly by realizing a sequence of a few Newton (second-order) iterations on the KKT conditions of the new problem.

The same scheme can be applied to nonlinear/nonconvex programs, but several obstacles can arise: iterations can stay stuck in an infeasible region, the Lagrange multipliers can be numerically unstable, etc. Many implementations introduce a second phase to deal with these drawbacks.

We have implemented a new approach in LocalSolver, originally developped by Hinder and Ye. The novelty is the introduction of a shift towards infeasibility into the barrier function. We discuss the practical advantages of this method, including the absence of a second phase (by juggling two variants of the Newton iteration), the tailored linesearch of the Newton step to deal with local nonconvexities and a good control of numerical instabilities, despite replacing equality constraints by two inequalities. We further control numerical errors due to bad conditionning by using Kahan summation.

We report numerical experiments on a nonlinear benchmark (558 instances, less than 250 variables). The interior points algorithm solves 90% of all instances, as compared to 60%/80% for the local-search/first-order approaches already present in LocalSolver.

■ TA-12

Tuesday, 8:30-10:00 - H1.51

Applied Combinatorial Optimization

Stream: Combinatorial Optimization I

Invited session

Chair: Dominique de Werra

1 - Graceful difference labelings of disjoint directed cycles

Christophe Picouleau

A graceful difference labeling of a directed graph G with vertex set V is a bijection f from the vertex set V to the integers from 1 to n (n being the number of vertices) such that, when each arc uv is assigned the difference label f (v) minus f (u), the resulting arc labels are distinct. We are interested in the case where G is a union of vertex disjoint directed cycles. When G is a collection of n directed vertex disjoint triangles, we show that G has a graceful difference labeling if and only if n is not one. The proof is constructive. Let t be the number of triangles. From the remainder of t divided by 7 four subcases are considered. Then the main ingredient is a recurrence in which the basic cases are from t equals 2 to t equals 9. Then we use this result to prove more general cases.

2 - Using Sankey diagrams to visualize the evolution of communities

Reinhardt Euler, Antoine Mallegol, Mehrdad Mohammadi, Patrick Meyer, Cécile Bothorel, Laurent Brisson

Information systems with complex and nested interconnections are often represented by diagrams making these systems easier to understand and interpret. Particular such diagrams are Sankey diagrams, a visualization tool allowing to depict quantities of flow from one node set to another through a set of links or edges. We use the concept of Sankey diagrams to study the evolution of communities over time in temporal social networks. Particular emphasis is given on temporal motifs such as expansion or contraction of communities, birth or death and especially merging and splitting operations where nodes are transferred from one community to another. Such motifs give an overview on group evolution and are useful to understand social behaviors for large audience communities like online political debates or to make decisions for publishing strategies through the monitoring of co-authorship research papers. The search for an optimal layout of such diagrams can be formulated as a combinatorial optimization problem closely related to crossing minimization in multi-layered graphs. We present and discuss numerical results obtained by solving this problem with hybrid methods based on genetic algorithms and simulated annealing. We also describe the data generator which provided the test instances of different size and configuration that we used to evaluate the performance of these methods.

3 - Shared Processor Scheduling

Wieslaw Kubiak, Dariusz Dereniowski

We study problem of shared processor scheduling of jobs. Each job can be executed on its private processor and simultaneously on possibly many processors shared by all jobs. This simultaneous execution reduces their completion times due to the processing time overlap. The goal is to maximize the total overlap of all jobs. This is a key problem in subcontractor scheduling in extended enterprises and supply chains, and in divisible load scheduling in computing. We introduce synchronized schedules that complete each job that uses some shared processor at the same time on its private and on the shared processors. We prove that, quite surprisingly, the synchronized schedules include optimal schedules. We review the problem complexity, optimization algorithms, and approximation algorithms with guaranteed approximation for the problem.

4 - Brexit, Grexit, Frexit ... A comparative study by the prism of persisting dominating set

Valentin Bouquet, François Delbot

Stimulating innovation and growth within the European Union is crucial and can be achieved by fostering R&D partnerships with EU Foreign Policies. Research collaboration networks induced by these policies received strong attention from policymakers. We showed that some structures from graph theory such as Minimum Dominating Set can be used to determine which members are most involved in these collaborative networks. They provide a better understanding of the impact of EUFP on collaborations induced between companies or research organizations. Although these networks are large in size, it is possible to determine optimal MDS. An MDS can be seen as the backbone of a network, allowing the transfer of information from one network member to another. In particular, we have shown that some vertices are present in each optimal solution and shown how to compute them. These vertices provide a better understanding of the structuring effect of the EU on collaborations between innovative organizations. This allows us, for example, to evaluate the impact of the withdrawal of an EU member on the collaborations' network (Brexit for example). In this paper, we propose a comparative study of the impact of the withdrawal of each of the European countries (in the broad sense by including some countries of the free trade area and of the candidates for entry into the European Union), i.e., 34 countries.

■ TA-14

Tuesday, 8:30-10:00 - H2.20

Decomposition Methods I

Stream: Mixed Integer Programming
Invited session
Chair: *Stephen Maher*
Chair: *Ibrahim Muter*

1 - Modelling and Solution Methods for Server Allocation Problem: An Application in Cloud Computing
Nursen Aydin, Ibrahim Muter, Ilker Birbil

Cloud computing is a new computing technology which allows users to customize their on-demand services. It can be defined as the delivery of computing services over the internet on a per-usage basis. Improving energy efficiency and lowering operational costs are the main challenges faced by such service providers. One prevalent objective in such systems is to minimize the number of servers required to process a given set of tasks under server capacity constraints. This objective leads to the well-known bin packing problem. In this study, we consider a generalization of this problem with a time dimension, where the tasks are to be performed with predefined start and end times. We address the virtual machine placement problem and present a binary integer programming model to develop different assignment policies. By analyzing the structural properties of the problem, we propose an efficient heuristic method. Moreover, we design a decomposition algorithm that yields a lower bound on the objective value, which can be utilized to evaluate the performance of the heuristic algorithm. Our numerical study indicates that the proposed heuristic is capable of solving large-scale instances in a short time with small optimality gaps.

2 - Branch and Price for Real-time Railway Rescheduling
Edwin Reynolds, Matthias Ehrgott, Stephen Maher, Judith Y. T. Wang

In railway systems, an initial delay to a single train can quickly cause other trains to become delayed by making the original timetable infeasible. This is called reactionary delay, and it accounts for 70% of all delays in the British railway system. Total reactionary delay following an incident can be reduced by re-scheduling: making good real-time decisions about how to cancel, re-route or re-time trains.

First, we present a microscopic integer linear programming formulation for this problem based on the multi-commodity flow problem. We then show how to solve it efficiently, using a tailored Branch and Price algorithm which was implemented using the SCIP solver. Finally, we describe a number of important acceleration strategies, and how they have been implemented.

3 - A subproblem selection strategy for the crew pairing problem with language constraints.
Frédéric Quesnel, Guy Desaulniers, Francois Soumis

Air crew rostering is usually performed according to a two-step sequential procedure: crew pairing and crew rostering. While the crew pairing problem (CPP) finds a set of low-cost feasible pairings, the crew rostering problem (CRP) uses those pairings to create a roster that abides by a set of rules. This talk focuses on language constraints, imposing requirements on the language skills of the crew composition of some legs. Such constraints are traditionally included only in the CRP. One shortcoming of the sequential method is that the pairings returned by the CPP may be incompatible with the language skills of the crews.

We propose a variant of the CPP, called CPP with language constraints (CPPLC), that includes soft language constraints (their violation is penalized in the objective) limiting the amount of work that can be performed in any language. The linear relaxation of the CPPLC is solved using column generation. One of the challenges in solving the CPPLC is the explosion of the number of subproblems. We, therefore, propose a subproblem selection strategy in which a small subset of these subproblems is solved at each column generation iteration. Different acceleration strategies are also put forward. We present results highlighting the performance of the method on several large-scale instances. We show that pairings obtained using the proposed method can significantly improve CRP solutions by decreasing the number of violated language constraints in the schedules.

4 - Optimization of Single and Parallel Batch Processing Machines
Ibrahim Muter

The batch-processing machine scheduling problem is one of the challenging problems in the machine scheduling literature where machines are capable of processing a batch of jobs simultaneously. Batch processing brings about complexities to the conventional machine scheduling problems in terms of the formation of the batches, which is carried out under machine capacity constraints. In this study, we tackle both single and parallel batch processing machine scheduling problems with the objective of minimizing makespan. The analysis of these problems unveils a strong relationship between the objectives of the parallel batch processing machine problem and the single machine counterpart. We propose a reformulation of the parallel machine problem and an exact algorithm for its solution. In the first part of the proposed algorithm, we solve the single machine problem by a column-and-cut generation algorithm. The second part employs a search mechanism to find the minimum makespan for the parallel machine problem, which entails the solution of the reformation by column generation.

■ TA-15

Tuesday, 8:30-10:00 - H2.32

Vector Optimization and Applications

Stream: Multiobjective Continuous Optimization
Invited session
Chair: *Christian Günther*
Chair: *Ernest Quintana*

1 - A Traffic Assignment Model With Parallel Links: A Multi-Objective Approach
Ovidiu Bagdasar, Stuart Berry, Sam O'Neill, Nicolae Popovici

Motorists often tend to choose the routes helping them to realise faster journey times. Route options between an origin and a destination may involve direct main roads (higher capacity, shorter, but easily congested), shorter routes through narrow side streets (often called 'rat-runs'), or longer (but potentially faster) journeys using motorways or ring-roads.

Here we first present some recent work concerning the interplay between the solutions of discrete and continuous optimisation and equilibrium-type problems, for a simplified traffic assignment model. This was formulated for a simple network with parallel links and fixed demand, under the assumption that the cost function only depends on time.

We then explore extensions of this model, first seeking to minimise the travel cost along each route (seen as a multi-objective function), then by considering multivariate versions of the cost function, accounting for the length of the road segments, pollution, or tolls.

2 - Using Parametric Sensitivity Analysis to Determine Pareto Fronts in Multi-Objective Programming
Arne Berger, Christof Büskens, Matthias Knauer

In order to solve non-linear multiobjective optimization problems, one usually solves multiple scalarized subproblems. This provides a discrete approximation of the Pareto front which gives useful information for the decision maker who has to select one single solution. In practice, however, this is often very time-consuming and requires a lot of computing power. In addition, it could be that the desired solution is not part of the precomputed discrete approximation, so one needs to apply interpolation techniques. This contribution shows how the information from the parametric sensitivity analysis of the scalarized subproblems can be used to gain as much information as possible about the local behavior of the Pareto front to support the decision maker on his way to the preferred solution. Furthermore, it is shown how the interpolation can be improved on the basis of this information and how the feasibility of the interpolated solutions can be guaranteed. The problems are solved with the NLP solver WORHP, which provides sensitivity information in an efficient way by reusing the factorization of the KKT matrix of the last optimization iteration. We show the basic functionality of the presented method by applying it to several multiobjective optimization problems.

3 - Duality for a New Class of Multiobjective Control Problems
Sorina Gramatovici

Multiobjective continuous control problems under generalized invexity assumptions have been widely studied during the last decades due to their large applicability in management science, portfolio selection, game theory, economic dynamics, as well as in engineering sciences. In Gramatovici (2005) we have established optimality conditions and duality theorems for continuous multiobjective control problems with one and two parameters, respectively, under generalized ρ-invexity. Recently, Kumar and Sharma (2018) established sufficient optimality conditions for multiobjective control problems using efficiency of higher order as criterion for optimality under ρ-type 1 invexity assumptions. Antczak et al. (2018) proved equivalence between a weakly efficient solution to a multiobjective variational problem and a weakly efficient solution to an associated modified multiobjective variational problem. Their results are obtained under univexity assumptions. In this paper we consider a new class of continuous multiobjective control problem for which we prove the equivalence between its higher order efficient solution and the higher order efficient solution to the associated modified control problem under ρ-type 1 invexity assumption. Weak and strong duality theorems are also proved for a mixed dual in order to relate higher order efficient solution to the primal and the dual problem. Our results generalize the results obtained by Kumar and Sharma and Antczak et al.

4 - A Penalization Approach for Vector Optimization Problems Involving Polyhedral Ordering Cones
Christian Günther, Nicolae Popovici, Christiane Tammer

This talk is concerned with vector optimization problems involving not necessarily convex constraints and generalized convex vector-valued objective functions that are acting between a real linear topological space and a finite-dimensional Euclidean space. We assume that the image space is partially ordered by a polyhedral cone. By using some relationships between vector optimization problems involving a polyhedral ordering cone, and multi-objective optimization problems involving the standard ordering cone, we are able to adapt the vectorial penalization approach derived by Günther and Tammer (2016, 2018) for multi-objective optimization problems to vector optimization problems involving a polyhedral ordering cone. It is shown that the set of Pareto efficient solutions of the original vector optimization problem can be computed completely by using two unconstrained vector optimization problems. The practical importance of our results is motivated by special location problems.

■ TA-16

Tuesday, 8:30-10:00 - Theatre A

Machine Learning and Combinatorial Optimization I

Stream: Combinatorial Optimization II
Invited session
Chair: *Roberto Montemanni*
Chair: *Matteo Salani*

1 - A survey of machine learning for combinatorial optimization
Gianni A. Di Caro

Application of machine learning (ML) is showing impressive results, with neural-network-based deep learning techniques (NNDL) leading the way. The aim of this work is to categorize how ML can be used in the solution of combinatorial optimization problems (COP), identify relevant literature, discuss opportunities and challenges. Different ML approaches can be used in COP depending on multiple factors: availability or not of labeled datasets, tackling single vs. multiple instances, searching for solutions with guarantees vs. heuristics, time constraints. We analyze which ML approach is the most appropriate depending on the scenario, and how it can be used. E.g., if labeled data are available offline, supervised learning (SL) can be adopted for heuristic solution, optimize hyperparameters of CO algorithms, replace expensive parts of a CO algorithm with fast approximations, predict running times or quality of result. SL can also be used online, exploiting data from a CO algorithm to learn relevant models for primal heuristics. In absence of a labeled dataset, reinforcement learning (RL) can be built into a CO algorithm to learn online a problem model or a policy. All ML use cases feature challenges including: choice of appropriate representation of problem state/instance (SL), which is particularly relevant to allow efficient use of NNDL; generation of a representative dataset either offline (SL) or online (RL); generalize out of training set; transfer learning across instances.

2 - Highway networks to solve medium-large TSP instances
Umberto Junior Mele, Roberto Montemanni

The Travelling Salesman Problem (TSP) is a well known NP-hard combinatorial optimization problem. It is one of the most intensively studied problems in the field and it is often used as a benchmark for testing new methods, and a large number of heuristics and exact algorithms have been proposed to solve it already. Recent research in Deep Learning shows that end-to-end learning approaches for combinatorial optimization problems provide promising results. Such methods are able to find suboptimal solutions with tiny optimality gaps very quickly, after proper training. The aim of this work is to introduce a novel deep learning infrastructure for the TSP. The approach uses Highway Networks gates that learn how to regulate the flow of information carried via backpropagation through several layers of Graph Attention Networks, avoiding the vanishing gradient problem. This allows the model to better select contributions from neighbours in the graph and to scale it to larger graphs. A Pointer Network architecture is used finally to implement the node selection mechanism. The architecture is based on a neural model able to learn the desired tour for a given TSP instance as a conditional probability of the possible tours given a hidden instance representation. This is achieved thanks to a structure similar to the attention mechanism. Experimental results will be presented.

3 - Machine Learning and Monte Carlo sampling for the Probabilistic Orienteering Problem
Roberto Montemanni, Federico D Ignazio, Xiaochen Chou, Luca Maria Gambardella

The Probabilistic Orienteering Problem is a stochastic optimization problem about the delivery or goods to customers. Only a subset of the customer can be served in the given time, so the problem consists in the selection of the customers providing more revenues and in the optimization of a truck tour to serve them. The presence of the customers is however stochastic, and this has to be taken into account while evaluating the objective function of each solution. Due to the high computational complexity of such an objective function, Monte Carlo sampling method is used to estimate it in a fast way. There is one crucial parameter in a Monte Carlo sampling evaluator which is the number of samples to be used. More samples mean high precision, less samples mean high speed. An instance-dependent trade-off has to be found. The topic of this presentation is a Machine Learning-based method to estimate the best number of samples, given the characteristics of an instance. Two methods are presented for the given problem and compared from an experimental point of view. In particular, it is shown that a less intuitive and slightly more complex method is able to provide more precise estimations.

■ TA-17

Tuesday, 8:30-10:00 - A005

Toward sustainable electric energy systems

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: Ruth Dominguez

1 - A sequential optimization model for municipal solid waste management
Giorgia Oggioni, Elisabetta Allevi, Adriana Gnudi, Igor Konnov

We propose a sequential model to analyze a sustainable supply chain where waste is collected by city municipalities and it is partially reused by a recycling company for the production of new goods. We consider a set of municipalities in charge of sorting the waste that can be either sold to the recycling company or sent to the landfill. Each municipality aims at maximizing its profit deriving from selling the sorted waste to the recycling company, taking into account the waste collection and dismantling costs. On the other side, the recycling company maximizes its profits arising from the difference between the revenues obtained from selling the new goods produced and the costs of purchasing and transforming waste. More precisely, we assume that the recycling company is able to produce electricity from organic waste, in addition to other goods derived from plastics. In this framework, the municipalities choose the prices at which they can offer waste to the recycling company, which, in turn, selects the processing volumes depending on these offer prices. In order to find the equilibrium of the whole supply chain, we propose an iterative method that account for the sequence of the decision taken by the municipalities and the recycling company.

2 - Transmission Expansion Planning Model of Energy Storage, TCSC and Lines Using Linearized AC OPF and Benders decomposition
Zora Luburić

Flexibility in the power system is very on the top of the observed measures that modern power systems need to deal with. The proposed methodology presents transmission expansion planning (TEP) problem into flexible assets, on one hand, such as battery energy storage systems (BESS), and Thyristor-controlled series capacitors (TCSCs), and on the other hand, in transmission power lines as a traditional investment option. The model uses a linearized form of AC OPF under Benders decomposition considering a Transmission System Operator (TSO) to be an investor of mentioned devices. The voltage magnitude, network losses, and reactive power are considered to bring an investor closer to the real power system conditions at the planning stage.

3 - Reserve provision by wind power units in the capacity expansion problem
Miguel Carrión, Miguel Cañas-Carretón

The active participation of wind power units in the ancillary services has increased significantly during the last years. Considering this, we formulate a novel coordinated generation and storage expansion problem considering that wind power units are able to provide a certain amount of reserve. The day-ahead energy and reserve capacity markets are explicitly characterized in this capacity expansion problem. The resulting stochastic mixed-integer linear problem is solved using commercial software. The proposed formulation is tested on a realistic case study based on an actual isolated power system in Spain.

4 - Applying Stochastic Dominance Constraints to Multi-Stage Capacity Expansion Problems
Ruth Dominguez, Sebastiano Vitali, Miguel Carrión, Vittorio Moriggia

To attain the net zero emission target by 2050 different energy strategies can be implemented. The use of stochastic dominance constraints allows to compare the results of each strategy from different perspectives. Therefore, in this work we carry out an analysis of the efficiency of the possible strategies to be followed to attain the emissions targets established by the European Commission for 2050. We present a multi-stage investment model in generating and storage capacity in which long-term uncertainties, such as the demand growth and the investment and fuel costs are considered, adopting the point of view of a central planner. The variability of the demand and the renewable production in the daily operation is taken into account by including a set of representative days of the year. Second-order stochastic dominance constraints are applied to select better strategies under different planning scenarios. In this work, we focus on the European power system and consider the predictions made by the European Commission to define the benchmark solution. The numerical results are based on real data provided by ENTSO-E.

■ TA-18

Tuesday, 8:30-10:00 - C112

Deep Learning Theories and Applications II

Stream: Multiple Classifier Systems and Their Applications
Invited session
Chair: Sureyya Ozogur-Akyuz

1 - The Complexity and Performance of Sparse Neural Networks with Threshold Activation
Junyoung Kim, Kyungsik Lee

Designing structures that balance expressive power and generalization capabilities is an important issue in neural networks. In this talk, we consider a single hidden layer feedforward neural network with limited connectivity between input and the hidden layer. First, we analyze the approximability and generalization bound of the proposed network using the concept of VC-dimension for proposed network structure, then make comparison with fully connected single hidden layer feedforward neural networks. Second, we proposed an incremental learning method based on column generation that adds a neuron to the hidden layer for each step and show that optimizing the proposed network with the hinge loss function and L1-regularization can be solved in polynomial-time for fixed connectivity. Finally, we examined the performance of the proposed network for multi-class classification task using benchmark data sets. Although it cannot be an universal approximator in theory, the proposed network has enough expressive power for real data sets and it shows comparable performance to existing feedforward neural networks.

2 - AlphaRouter - Detailed Routing Model Using Reinforcement Learning
Upma Gandhi, Erfan Aghaeekiasaraee, Ismail Bustany, William Swartz, Laleh Behjat

Chips in very large-scale integrated circuit design are a sea with millions of logic gates and nets. The nets manifest as physical interconnect wires that connect logic gate pins and/or I/O ports together. The detailed routing problem is NP-hard, and its complexity is further magnified by its large scale. Traditional methods for solving it use optimization algorithms or heuristic methods built on shortest path algorithms. Due to the complexity and large scale of this problem, it is extremely hard to come up with efficient solutions. We propose an alternative approach, the AlphaRouter. The AlphaRouter is based on reinforcement learning (RL) inspired by work in AlphaGo. AlphaGo defeated the Go Game World Champion without human input. AlphaGo uses a probabilistic look-ahead horizon scheme based on a Monte Carlo Tree

Search (MCTS) to select its next move. The move probabilities from MCTS are fed to a (deep) neural network which updates its weights according to the win and lose outcome. AlphaRouter self-trains with help of a neural network having similar architecture used in AlphaGo. The data that is fed into the neural network is produced by self-plays. We present a model that shows how AlphaRouter works on a simplified circuit and then move to real world benchmarks for the detailed routing problem. Our goal is to compare both efficiency and quality of solutions stemming from this self-learning machine with the solutions obtained from traditional optimization techniques.

3 - Deep-Learning-Based Dynamic Dispatching for a Highly Work-Loaded AMHS in a Semiconductor Fabrication
Dae-Eun Lim, Haejoong Kim

Recently, the transportation capability of the automated material handling system (AMHS) has emerged as a major bottleneck to the semiconductor fabrication facility (FAB), because it can lower the production capacity of the FAB. This study proposed a deep learning-based adaptive dispatching method for facility scheduling in consideration of the limitations of the AMHS's transportation capability. It is a method to allocate facilities dynamically depending on the state in order to overcome the limits of the widely-applied static dispatching rule. In this case, the state was determined in consideration of not only the processing time of the process and the condition of equipment, but also transportation time by the AMHS, distribution of WIP distribution and storage. This study proposed a learning-based dispatching rule to maximize facility utilization rate and fab throughput by considering these states when dispatching is performed. This study compared the proposed model with the existing dispatching rule and analytic model under the various experiment conditions, and the results showed that a higher uncertainty in the FAB showed a better performance.

4 - Accident Pattern Extraction from Qualitative and Quantitative Data Using Non-linear Principal Component Analysis (NLPCA) and K-means Clustering
Krantiraditya Dhalmahapatra, Kritika Singh, Praveen Kumar, J Maiti

Visual analytics has been used by several researchers for analysis of accident/incident data to explore the causal factors of accidents. However, these methods fail to quantitatively capture the data inconsistencies. Dimensionality reduction and clustering are the two multivariate exploratory methods used for meaningful pattern extraction and subsequent rule generation. In this respect, many statistical techniques proved to be efficient while dealing with quantitative data but these failed to give satisfactory results in case of a mixture of qualitative and quantitative data. Principal Component Analysis (PCA) assumes the data to be quantitative and hence, it is not directly applicable to qualitative data such as nominal and ordinal data. So, in this work, we have used Non-Linear Principal Component Analysis (NLPCA) for mixed-type data. It reveals nonlinear relationships among variables and hence, a more flexible alternative to ordinary PCA. This research provides a decision making framework for safety rule generation by analysis of cross-sectional and temporal data to extract the hidden association amongst the attributes in a data set using NLPCA and K-means clustering. In NLPCA, solution methodology involves minimization of two types of loss functions; a low-rank approximation and homogeneity analysis with restrictions. After dimension reduction, K-means clustering is applied to obtain optimal clusters and safety rules to prevent incidents in the steel making industry.

■ TA-19

Tuesday, 8:30-10:00 - C115

Emerging Collaborative Economics and Management under Uncertainty 1

Stream: Emerging Collaborative Economics and Management under Uncertainty
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Milagros Baldemor*

1 - Planning travel itineraries via statistical and operations research techniques
Vitoria Pureza, Admilson da Silva, Reinaldo Morabito

Touristic activities in Brazil generated a turnover of approximately US$4.4 billion in 2014, representing a market of six million tourists traveling around the country. Motivated by these figures, we address the problem of elaborating travel itineraries by taking into account not only travel distances and costs, but also the visitors' profiles, how much the tourists value the attractions offered, as well as their preferences regarding the order of visiting these attractions. We propose an optimization model based on mixed integer programming to generate itineraries that maximize the total value of the attractions visited and minimize the total travel cost involved. We also present results for instances based on randomly generated and real data by applying mathematical programming techniques and a matheuristic. The input parameters for the real cases were obtained by applying some statistical techniques to the data collected, such as multivariate correspondence analysis. The resulting solutions illustrate the potential application of the proposed approach.

2 - Spatiotemporal nature of coordination with ridehailing platforms
Harit Joshi, Saral Mukherjee

The emergence of ride-hailing platforms which act as two-sided markets connecting independent crowds of driver and riders has deeply impacted the way taxi operations are coordinated. From traditional decentralized taxi models where drivers and riders acted independently, now we have centralized coordinator reducing information search costs by optimally matching them.

In this study, we quantify the value of coordination provided by the centralised coordinator to the two key stakeholders in ride haling. A riders' objective is to minimise the total service time while drivers try to maximise their utilization. We build an agent-based model of a road network with riders and drivers to compare the performance of a centralised model to a decentralised model in terms of the objectives of drivers and riders. Using our model we identify the impact of spatial and temporal attributes of the customer demand and of the network geometry on the value provided by the centralization. We compare the value for the rider and for the driver and identify decision rules and parameters that favour one over the other or are optimal for both.

This understanding of the value of coordination provides input for decision making for the ride-hailing platforms and policymakers in prioritizing their efforts while planning ride-haling based models for a city.

3 - New challenges in predicting prices of oneline auctions
Esma Gaygisiz, Emrah Öz

Current technological developments have changed our trading habits and the importance of e-commerce in our lives has grown rapidly in the past decade. This new economic and technological environment generates easily accessible massive and very valuable data. In this context, this study analyses auction sales in some smartphone markets, realized in 2018, using machine learning algorithms. The study shows how vendors' product descriptions play an important role in the determination of sale prices using sentiment analyses and clustering algorithms. In addition, the findings emphasize the significance of the price information of similar products and time dependent dynamic characteristics of the auctions in the prediction of auction prices with a challenging perspective.

4 - A new Approach to the Coupon Collector's Problem with Collaboration, Swapping and additional Purchases
Tobias Baumgaertner, Dorothea Calmels, Nikolai Holeczek

The coupon collector's problem is a well-known stochastic optimization problem that is receiving particular attention every four years during the Football World Cup. Assume a collection of distinct coupons or items. At each independent draw, an item is drawn with a fixed probability. The process is repeated until all coupons have been collected. In reality, multiple collectors aim for the same objective of completing the collection and they collaborate by swapping duplicate items. In this article, a variation of the coupon collector's problem is studied. Each collector already possesses individual stocks of items and duplicate items. The collectors are assumed to be friends and are willing to split up the duplicate items among themselves; therefore, the collectors want to maximize the number of items assigned to all players and at the same time to balance the number of items received by all players in order to minimize the total cost of completing the albums. Further, they collaborate by creating a common stock of duplicates and missing items that they trade with other collectors. A mathematical model as well as a greedy heuristic procedure are presented and evaluated for a set of problem instances based on the collection of football stickers. It is shown that the heuristic efficiently balances the maximum number of collected items among all collectors.

■ TA-20

Tuesday, 8:30-10:00 - C006

Business Analytics I

Stream: Business Analytics
Invited session
Chair: *Kristof Coussement*
Chair: *Dries Benoit*

1 - Customer Life Event Prediction
Arno De Caigny, Kristof Coussement, Koen W. De Bock

Life events, such as the birth of a child or moving, can cause major shifts in the relation with customers. Companies, however, often only react after the customer encountered a certain life event. Companies can create substantial competitive advantages by accurately predicting life events because it enables them to pro-actively act on potential shifts in the customer relation. In this study, structured and fine-grained behavioral data of a large European financial services provider are used to predict four different life events. The fine-grained behavioral data, i.e. payment transaction logs, are analyzed by means of pseudo-social networks from which predictive behavioral similarity scores are derived with respect to the different life moments. The contributions are twofold. First, this study is the first to demonstrate the prediction of life events in a real-life setting. Second, the results of this study show that fine-grained behavioral data and structured data should be combined.

2 - Using Social Network Analytics to Improve Subscriber Preference Predictions in the Context of Digital Publishing
Klaas Nelissen, Seppe vanden Broucke, Bart Baesens, Monique Snoeck

We assess the value of using Social Network Analytics to improve preference predictions in the context of digital publishing. We assess the value of constructing a social network of newspaper subscribers and using that information next to historical reading behavior in order to improve the performance of predictions for the subscribers' preferences.

The main contribution of this paper is twofold. First, we show the value of using Social Network Analysis applied on a pseudo-social network in a new application setting to improve the performance of predictive models in this novel context of digital newsreaders' preferences. Secondly, we demonstrate the benefit of constructing a pseudo-social network of subscribers based on popularity-adjusted relative similarities of reading behavior.

We use historical data about the individual historical reading behavior of digital newspaper subscribers to construct a pseudo-social network. Subsequently, we build different types of predictive models based on different sets of intrinsic and network-based variables.

We conclude that the benefits of adding variables based on social network analytics in terms of increased predictive performance are significant. It is essential for publishers and media companies in the industry to be aware of the opportunities present in leveraging social network analytics for predicting their readers' preferences.

3 - Detecting Online Student Dropout: A Machine Learning Approach
Trung Hoai Minh Phan, Kristof Coussement, Dries Benoit, Arno De Caigny, Annelies Raes

Online learning has been adopted rapidly by organizations and educational institutions. Despite having many advantages like easy access, high flexibility, rich content and low cost, online learning has been suffering from students stopping their learning experience. High dropout rates also affect negatively the educational and business goals of the online learning providers. Therefore, by helping students complete their learning experience, online learning providers do benefit from a student dropout prediction system. This study, conducted in the context of predicting dropouts in a subscription based online learning environment, benchmarks the recent Logit Leaf Model algorithm with six benchmark algorithms on a real-life student dataset from a well-known online learning provider. According to the results, (i) it is feasible to predict the student dropout with good predictive performance; (ii) the predictive performance of the comprehensible Logit Leaf Model is equivalent to the top three, more complex, benchmark models; (iii) the interpretation of the Logit Leaf Model segments gives insights into the different groups of students with different learning patterns, which can be used to tailor the student retention campaigns.

4 - Evaluating Multi-Label Classifiers and Recommender Systems in the Financial Service Sector
Matthias Bogaert, Dirk Van den Poel

The objective of this paper is to evaluate multi-label classification techniques and recommender systems for cross-sell purposes in the financial services sector. We carried out three analyses using data obtained from an international financial services provider. First, we tested four multi-label classification techniques, of which the two problem transformation methods were combined with several base classifiers. Second, we benchmarked the performance of five recommender approaches. Third, we compared the best performing multi-label classification and recommender approaches with each other. The results identify user-based collaborative filtering as the top performing recommender system. Classifier chains binary relevance with adaboost and binary relevance with random forest are the top performing multi-label classification algorithms. Our study provides important recommendations for financial services providers, who are interested in the most effective methods to determine cross-sell opportunities. Our study is the first to compare both techniques in the financial services sector.

■ TA-21

Tuesday, 8:30-10:00 - F101

Lot-sizing VI - Integrated lot-sizing and scheduling

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: *Gorkem Yilmaz*

1 - Lot sizing and scheduling problem with delivery time windows
Maristela Santos, Willy Alves de Oliveira Soler, Kelly Cristina Poldi

This research addresses a lot sizing and scheduling problem inspired by a real-world production environment. Customers make advanced orders and the decision makers need to decide which orders will be accepted with the aim to maximize the profit. Orders are composed of different items which must be delivered within a given time interval and they cannot be splitting. A mixed integer programming model and a MIP-based heuristic composed of three phases (construction, deterministic improvement and stochastic improvement phases) were developed to deal with the problem. Computational tests show that the proposed heuristic performs better than the Cplex solver to provide good solutions at the acceptable computational time.

2 - Explicit Modelling of Multi-Period Set-up Times in the Proportional Lot-Sizing Problem with Variable Period Length
Waldemar Kaczmarczyk

In the lot-sizing and scheduling, periods are usually equal to the longest time interval which makes it possible to describe the external demand. In many multilevel systems, i.e., with dependent demand or multiple processing stages, lead times are much shorter than a single period. If modeled lead times are equal to one period, the solution is feasible, but production cycles are long. If lead times are zero, cycles are short, but the solution may be infeasible.

Both, short cycles and feasible solution, may ensure a model in which each period is split into several short fictitious microperiods, with nonzero demand only in the last microperiod in each period. However, such a model has two other disadvantages. First, the number of binary variables and related computational effort is higher. Second, the microperiod length may become shorter than the set-up time.

To overcome these difficulties, I propose a new Mixed Integer Programming model for the Proportional Lot-sizing and Scheduling Problem with set-up operations overlapping multiple periods of variable length. It assumes that most periods have the same length, but a few are shorter than usual and the gap between two shorter periods is always longer than a single set-up operation. It explicitly determines the last period overlapped by each set-up operation. Presented results prove that the new model requires a much smaller effort to compute the optimal solution than known models.

3 - A Column Generation Approach for Lot Sizing and Scheduling Problem
Gorkem Yilmaz, Cevdet Utku Şafak, Erinc Albey

In this study we develop a mixed integer programming (MIP) model that simultaneously handles capacitated lot sizing problem with sequence dependent setups (CLSD) and scheduling of a plastic injection plant over a multiple periods. The problem consists of parallel non identical sets of machines using multiple sets of non-identical molds that can be mounted on the machines with minor and major setup time requirements considering setup carryover between periods. The setup carryover extension of the CLSD problem is handled by revising the original MIP model as a mixed integer quadratic programming (MIQP) model considering the setup carry over capacity loss. In order to solve industry sized problems, we propose a heuristic approach based on column generation. The dual information of the linearized MIQP model is used to generate promising columns to be included in the next iterations. Computational results based on real data of Vestel Electronics plastic injection plant show that the proposed algorithm can be used to tackle very large instances (e.g. 87 machines and over 1000 orders for over 400 products produced by over 300 molds for 14 periods). Proposed methodology provides superior solutions compared to that of current scheduling approach used in the company.

4 - Discrete Production Lot Sizing and Scheduling Models for Conflicting Items
Julia Pahl, Stefan Voss

In many industries, requirements often imposed by regulations imply extensive cleaning of production equipment and separate storage of items, so that contact with other products is avoided of products sensitive to contamination. Examples of such products can be found in the food industry concerning allergens, but also in healthcare regarding hygiene. For instance, certain products such as syringes cannot be stored together before packaging, because they can lose their antiseptic state if stored close to erroneously produced syringes that may contain germs. The latter can be reworked in a time window of ca. 48 hours after production but need to be discarded once this time window is closed. Examples in the food industry include an-allergenic food items that are produced on the same machines as regular food items containing allergens, so that intensive cleaning and sanitizing of equipment is mandatory. In this paper, we are interested in analyzing the effects of conflicting items in mathematical optimization models. Therefore, we study the generalized lot sizing and scheduling problem (GLSP) with rework including constraints on production sequences regarding conflicting items as well as limited lifetimes of contaminated items that need sanitizing. Other constraints include limited storage space of conflicting items. We analyze how these constraints affect solution finding in terms of model complexity.

■ TA-22

Tuesday, 8:30-10:00 - F102

Production Planning and Control for Complex Manufacturing Systems

Stream: Production Planning and Control for Complex Manufacturing Systems
Invited session

Chair: *Stéphane Dauzere-Peres*
Chair: *Cathal Heavey*
Chair: *Lars Moench*
Chair: *Thomas Ponsignon*

1 - A key performance indicator for product allocation to customers for semiconductor industry
Behrouz AlizadehMousavi, Radhia Azzouz, Cathal Heavey

Dynamic demanding industries like semiconductor manufacturing are characterized by demand variations due to the shortening of product life cycles amplified inside the supply chain by the bullwhip effect. However, customer satisfaction requires trustable forecasts as well as accurate order promising processes. Demand and supply fluctuations cause companies to face customers' demand exceeding the available supply. Thus, distributions of available supply between the customers should be ensured. The goal is to achieve given commitments and avoid line downs. In addition to proposing efficient allocation algorithms, there is a need for accurate Key Performance Indicators (KPIs) to measure the success of this process. In this paper, a KPI to assess the quality of a customer allocation plan is developed. Since short supply is faced, demand fulfilment KPIs such as delivery reliability could not be used. Thereby we propose a performance measure depending only on how fair and equitable allocations to customers are. Although customers' priorities should be considered, maximizing customer satisfaction needs a supply distribution proportional to customer orders. Moreover, a use case study based on a semiconductor manufacturer in Ireland is considered where this allocation process is handled manually based on allocation managers' experiences. As well there are no KPIs to evaluate the quality of the proposed allocation plans. The result of this study will support allocations decisions

2 - Application of a Random Forest decision support system to a bio-pharmaceutical manufacturing process
Will Fahey, Paula Carroll

Yield fluctuation is one of the most challenging issues facing biopharmaceutical (BP) manufacturers. Extracting insight from manufacturing datasets using Business Analytics is one way of addressing this challenge. Data is monitored and stored as part of the regulatory requirements of the manufacturing process, but this data may also hold the key to improved process performance. We categorise data into online and offline measurement. Online measurement generates data from sensors and is available real time. Offline measurements require a sample of the batch to be taken and sent to the lab for analysis. If process behaviour is to be described accurately both categories should be considered. We use a Symbolic Aggregate Approximation (SAX) approach to reduce the online time series data. The SAX representation of the time series is then passed to a data mining (DM) algorithm. With the emphasis on achieving actionable insight from the data that can be readily implemented on the manufacturing floor, Random Forests are selected as the DM approach. In this case, we are prepared to sacrifice optimum data mining performance to ensure the interpretability of the results. We summarise results from a case study using this approach and highlight how our business analytics approach extracts actionable insights into the BP yield fluctuation problem.

3 - An Iterated Min-Max Procedure for Practical Workload Balancing in Manufacturing Systems
Quentin Christ, Stéphane Dauzere-Peres, Guillaume Lepelletier

Workload balancing is an important problem in many systems with multiple resources, in particular in manufacturing systems. The goal is to balance product quantities to process on various potentially non identical machines. We first show the limitations of classical models in an industrial context. Then, we introduce and motivate the min-max fairness workload balancing problem, and present an original approach to solve this problem. Computational results on industrial instances show the relevance of the approach, and its current use in an industrial tool is also discussed.

4 - Simulation -Assisted Decision Making for Supply Chain Disruptions in Production Control
Andreas Schlereth, Thomas Ponsignon, Axel Bruns

Supply chain disruptions with an unpredictable occurrence such as significant differences between forecasts and actual customer demands are challenging for semiconductor manufacturers. Normally, these events are responded to with a time-consuming mostly manual procedure. This work describes an approach for an automated framework to react faster and with less effort on these unpredictable events. Implementing this framework, a service oriented architecture is used. It consists of multiple services for receiving events out of the supply chain, enrich them with additional data coming from production IT systems such as MES, analyze them and make an actual decision, which is then forwarded to a dispatch proposal application. To evaluate the automated decisions, the use of simulation is necessary. Therefore, a discrete event simulation and a simulation based on a system dynamics approach have been combined. As a result of this framework's approach, safety stocks can be reduced due to a more accurate cycle time prediction and a reduced number of false alarms regarding supply chain disruptions.

■ TA-23

Tuesday, 8:30-10:00 - F103

Forecasting in Retail

Stream: Demand and Supply Management in Retail and Consumer Goods
Invited session
Chair: Winfried Steiner

1 - Accommodating nonlinearities and dynamics in store-level price response models
Philipp Aschersleben, Winfried Steiner

It is well-known that store-level brand sales may not only depend on contemporaneous variables like current own and competitive prices or other current marketing activities, but also on past prices representing customer response to price changes. It has further been shown that accounting for lagged prices in a sales response model can increase expected brand profits over a static model that ignores price dynamics. On the other hand, non- or semiparametric regression models have been proposed in order to accommodate potential nonlinearities in price response, and related empirical findings indicate that price effects may show complex nonlinearities that are difficult to capture with parametric models.

We combine nonparametric price response modeling and dynamic pricing. In particular, we model sales response flexibly using a Bayesian semiparametric approach and include the price of the previous period as well as further time-dependent effects. All nonlinear effects are modeled via P-splines, and embedding the semiparametric model into a hierarchical Bayesian framework further enables the estimation of store-specific (lagged) price response curves. In an empirical study, we demonstrate that our new model provides both more accurate sales forecasts and higher expected profits as compared to competing models that either ignore price dynamics or just include them in a parametric way. Optimal price policies for brands are determined by a discrete dynamic programming algorithm.

2 - Dynamic Effects of Store Promotions on Purchase Conversion: A Prediction Approach
Leonardo Epstein, Ignacio Inostroza-Quezada, S. Chan Choi

We present a new method to evaluate the effects of promotions on conversion probabilities, namely, the probability that a store visitor makes a purchase while at the store. Conversion is a key measure of promotion effectiveness. The method uses arrival and purchase counts in time bands within a day, for instance one-hour bands. Then, it builds a counterfactual baseline with predictions of the number of purchases in each time-band during the promotion interval, conditional on the hypothesis that the promotion did not take place. To evaluate the promotion, the approach uses the differences of appropriately transformed predictions and the corresponding appropriately transformed observed counts of purchases, which we call prediction residuals. To compute the predictions, we use only pre-promotion data and Beta-Binomial regression models where co-variables include time-band within a day, day of the week, week of the month and month. The talk presents graphical tools to help managers visualize the effect of a promotion on conversion. Some advantages of the approach are 1) does not require a model for the promotion effect, often difficult to obtain since the distribution of the data prior and during the promotion may differ markedly, and 2) provides and adjusted overall effect on conversion at the end of the promotion. An illustration combines arrival data from video images and sales recorded at the sales register.

3 - Prediction of sales dependent on temperatures
Aleš Kresta, Tomas Tichy

In this contribution, we focus on prediction of sales in ice category. Sales in this category are assumed dependent on the temperatures (average or maximum), thus we first study the dependence between the sales and average and maximum temperatures utilizing quarterly data. From the results, we can conclude that there is statistically significant dependence in the form of exponential function. Then we focus on prediction of temperatures and study the influence of its misprediction on the sales. Particularly, we focus on two approaches: simple linear regression model and LFL-Forecaster, a method combining fuzzy transform and fuzzy natural logic of fuzzy sets theory. We model both the average and maximum temperatures with monthly and quarterly frequencies. The dataset of the temperatures consists of monthly data over the period 1961-2018. In our analysis, however we focus on period 2008-2014 and 2015-2018. In the first period, we know truly observed sales and temperatures, while in the latter we know only truly observed temperatures. From the results, we found out that the application of LFL-Forecaster shows significant improvement over simplifying linear regression model.

4 - Demand forecasting in the context of intra-cannibalization
Hing Kai Chan, Shuojiang Xu

In order to maintain the competitiveness of the company in the market, it is necessary to continuously launch new products or upgrade existing products. However, these new products will grab some or all of the sales from existing products. This phenomenon is called intra-cannibalization. When a new product is launched, there may be a significant change in the sales of the existing product. Most of the existing forecasting models are based on the stationary time series, and there is no good way to forecast the time series with obvious trend changes. It is necessary to build the demand forecasting model in the context of intra-cannibalization. We proposed a demand forecasting approach which adopts the cannibalization rate as the indicator to improve the forecasting accuracy.The proposed approach is able to calculate the intra-cannibalization rate and generate more accurate forecasting results compared with existing models. The approach proposed in this study first adopts the cannibalization rate into demand forecasting approach, which plays an important role in improving the forecasting accuracy

■ TA-24

Tuesday, 8:30-10:00 - F103A

Combinatorial Optimization Problems emerging in Supply Chain Management

Stream: Supply Chain Management
Invited session
Chair: *Ibrahima Diarrassouba*

1 - Optimal design of a medical goods supply chain
Ibrahima Diarrassouba, Adnan Yassine, Hamdi Dkhil

In this work, we study the design of a supply chain of medical goods, especially in the case of several hospitals which have to share resources for reducing storage and supply costs. Such a problem arises in the context where the authorities create clusters of hospitals which are located in the same geographic region. The purpose of each cluster is to share warehouse, inventory, supply and transportation features for their medical goods consumption.

Here, we consider a supply chain composed of several hospitals, several suppliers and a central hub. Each hospital can satisfy its medical goods demand by directly from the suppliers, or by passing through the central hub. By passing through the hub, the hospitals can benefit from scale economies effects, and may reduce the overall supply cost.

In this work, we consider the problem of determining an optimal supply strategy for each hospital of a cluster. The goal is to satisfy the demands of the hospitals while minimizing the overall supply, storage and transportation cost. We first give a generic mathematical formulation of the problem. Then, we consider particular supply and storage cost structure s, and provide resolution algorithms.

We also consider the problem in a decentralized context, that is when each hospital of the cluster decide its strategy independently from the others, and discuss some issues related to this particular aspect.

2 - Approximate Analysis of Flow Line with Assembly Considering Unreliable Machines and Parts Supply
Yang Woo Shin, YuWon Seo, GyeongMin Baek, Dongok Kim, Dug Hee Moon

Consider a flow line in which multi-stations are linked in series. Each station consists of single unreliable machine and two finite buffers, one for product and the other for part to be assembled. The product is supplied to the first workstation of the system and they are processed along the line, and a part is supplied to each station according to independent Poisson processes. The machine operates only when a product and a part are prepared. Blocking-After-Service (BAS) rule and Operation-Dependent-Failure (ODF) rule are assumed. The processing time, failure time and repair time of each machine are assumed to be exponential and independent. In this study, we present an approximate analysis for the throughput of the system based on decomposition method with two-server-one-buffer subsystem. The state space of the subsystem in our approach contains not only the states of the machine such as blocking, starvation and working but also the states of parts and partial information of the buffer state of upstream buffer. Some numerical examples are presented for effectiveness of approximation.

3 - An Integer Linear Programming Approach for Solving the Combined Cell Layout Problem
Kerstin Maier, Miguel F. Anjos, Philipp Hungerländer

In this work we consider the Combined Cell Layout Problem (CCLP). The CCLP aims to minimize the material-handling costs in a cellular manufacturing system with two or more cells where processing occurs, and in the presence of parts requiring processing in more than one cell. The alignment of the machines in each cell can follow a row or a circular layout. The CCLP was first introduced by Hungerländer and Anjos in 2012 who suggested a Semidefinite Programming (SDP) approach for solving it. We propose an Integer Linear Programming approach for solving the CCLP. Finally, we create a large benchmark set and demonstrate the efficiency of our ILP on these instances in a computational study. We show that our approach is able to solve instances with up to 240 machines arranged in 10 cells to optimality within one minute. Hence, it outperforms the SDP proposed by Hungerländer and Anjos, which was the current best available exact approach.

■ TA-25

Tuesday, 8:30-10:00 - F104

Manufacturing

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: *Jingshan Li*

1 - An Empirical Study on Lean Performance Parameters of Manufacturing Sector in India
Lokesh Vijayvargy

Growth and GDP of any nation is depend on its in-house manufacturing capacity. Due to manufacturing China, Japan, USA, and Korea are leading world in growth and employability. But due to low cost and govt. policy, India is coming with new emerged area for manufacturing hub in world. India has launched many strategy to increase investment and employability in manufacturing sector like: Make in India, Start up India, Digital India etc. there India is one of the most lucrative option for manufacturing industry to prosper. This paper will help us in identification of lean performance parameters of manufacturing companies of Rajasthan (biggest state area wise). 100 manufacturing companies has been surveyed in various areas of Rajasthan, India. This paper draws conclusion on productivity, effectiveness, lead time, quality, flexibility, inventory, and some other issues. Many types of manufacturing industry like textile, soap, fabrication, plastic bag, coal mining, diamond, pipe, ice-cream etc is included in our research. The respondent has different position in organization like HR, manager, owner, director, etc. The outcomes of the research work offer the important implications for the Indian manufacturing organizations to understand the factors affecting their performance.

2 - Application of Lean Project Management in Construction: A Review of Performance Improvement
Mohammed Alhalafi, Parminder Singh Kang

Although, Project management planning and completion are a prerequisite to achieve pre-determine awarded project, be it construction or otherwise, the factors responsible for the delay in delivery are overwhelming. Literature reveal that material process delivery, material defect, weather condition, inadequate workforce, substandard raw material from suppliers and accidental breakdown of machine could potentially delay a completion and delivery of a project which can result to overrun cost and rework additional budget. Construction projects have received massive criticism in recent years due to poor performance and low productivity, which make it apparent for the integration of lean project management in the construction sector. The construction industry in Saudi Arabia is not exception to the process of implementing the strategies for which delay in construction is mitigated. Lean concept and principles are considered the apex solution for the minimisation of waste and removal of delay time that always result to cost overheads. The data collected for the research include a review of literature from current academic sources and the application of a mixed method where a qualitative and quantitative data collection was adopted, and the result is integrated to have a rich data that was complemented with literature reviews. The semi-structured face-to-face interview survey targeted to

3 - The changes in the Value Chain of production due to 3D printing manufacturing technology
Evgenia Fronimaki, Maria Mavri, Vissarion Christodoulou

Additive manufacturing (AM) creates physical complex objects from a geometrical representation by successive addition of material in a single process step. The benefits of 3D printing (3DP) methodology include new design freedom, removal of tooling requirements and economic low volume. Customized products, products with difficult geometries and components of products from scratch can now be designed and printed with AM. Small or big markets can be served without requiring companies to warehouse or produce goods at large costs. The result of this technology is the redefinition of production systems as the new production line is the combination "Design-Sales-Printing". Moreover, the use of personal 3D printers could not only change the manufacturing methods but could also reshape business processes from the design of an object to its consumption. AM is a technology that has the potential to change the future of supply chains and how industries design, manufacture and/or repair goods in the future. 3DP will affect every area of the manufacturing value chain: Design; Manufacturing; Supply chain; and Distribution. The goal of this work is: 1) to describe the new ecosystem of 3DP technology and the changes that will be occurred at production chain; 2) to enlighten the corresponding changes at value chain. In order to meet these goals, we try to identify factors that affect aspects of 3DP manufacturing procedure such as operations, logistics, marketing, HR and infrastructure.

4 - Aggregation Algorithm for Flexible Bernoulli Lines with Dedicated Finite Buffers
Jingshan Li, Kyungsu Park

Due to rapid market changes and customized demands, flexibility of production lines become essential in modern manufacturing industry. We thus develop an efficient method for performance analysis in flexible manufacturing systems while considering unreliable Bernoulli machines, scheduling policies and dedicated buffers. We develop an aggregation approach and an iterative method that repeatedly aggregates a pair of two machines into one machine until the whole line become one aggregated machine. By repeating these iterations until convergence, we obtain the estimation of system throughput. It is shown that such an approach provides acceptable accuracy for system performance with small computation time. Therefore, such an algorithm can be used by production engineers to analyze flexible manufacturing systems.

■ TA-26

Tuesday, 8:30-10:00 - F106

International Aspects of OR I

Stream: International Aspects of OR
Invited session
Chair: *Narasimhan Ravichandran*
Chair: *Ulrike Reisach*

1 - MCDM techniques for the restoration of phosphorous ponds at Huelva estuary (Spain)
Antonio Jiménez-Martín, Danyl Pérez-Sánchez, Alfonso Mateos, Roser Sala, Christian Oltra, Silvia López

Phosphate production in Spain dates from over a century ago. Although Directive 96/29/EC was transposed into Spanish legislation, no radiological controls on effluent monitoring and release, or on waste disposal for that matter, have yet been enforced in Spain. Nevertheless, over the last thirty years, the radiological environmental impact of all phosphate facilities in Spain has drastically decreased as an indirect result of the enforcement of legal instruments on chemical pollution prevention and control set into action. The two mainly phosphoric acid production plants in Spain are located in Huelva (Andalusia) and apply the wet production route through digestion of the phosphate rock by sulphuric acid. In this work we apply MCDM tools for the restoration of the phosphorous ponds of Huelva estuary, taking into account economic, social, environmental and radiological aspects. We consider a multi-attribute utility model that accounts for imprecision concerning the remediation alternative impacts and uncertainty about the DMs preferences by means of a linguistic term scale, ordinal information about the relative importance of criteria and fuzzy and interval values. Different remediation alternatives are analysed, such as the remediation in situ, using the conditioning of the pounds and vegetation cover and other alternatives, the removal of this waste to landfills of conventional waste or its reuse in other applications as material to amend soils, construction, roads…

2 - Differences between Chinese and American Teaching and Research Methods in University
Shaodong Wang

This presentation will compare teaching and research approaches in the USA and China. Based on the literature, observation, and a small empirical study by using questionnaires and setting interviews among Chinese students in the USA, I will explain the reasons and consequences of those two different study environments for students as well as for the innovation path of both countries. Firstly, I will analyze how professors in universities in China and the USA teach students and do research in OR and how students interact, following with some problems and shortcuts of Chinese professors and students when compared with the USA in this process. Secondly, the differences will be explained according to different criteria and contextual factors. Two of the main influencing factors, the educational system, the common philosophy of practice of Chinese and American people will be highlighted and examples of well-performed teaching and research approaches by Chinese professors given. Additionally, best practice examples of approaches applied by professors in the US will be shown. The presentation summarizes with potential learnings that could be drawn from both approaches.

3 - Traffic Optimization in China and Europe - A Comparison of Systems and Approaches
Ulrike Reisach

China is the world's largest and fastest growing market for e-mobility. In order to create a deeper understanding of smart city concepts, data-based traffic optimization models, their efficiency and environmental impact, the speaker organized a field trip of the study program Information Management Automotive to China in November 2018. The main goals of the field trip were (1) to understand industrial policy and market specifics in public and private transportation systems, (2) to learn how China supports and regulates e-mobility and how it succeeds in building up the relevant infrastructure incredibly fast and (3) to discover how local and foreign companies deal with the opportunities and challenges of this huge market. The group experienced the local public transportation systems in four megacities and analyzed their benefits and shortcomings from a user's perspective. They visited nine e-mobility companies and three universities to learn from their experience and strategies. Additionally, the researcher interviewed two traffic planners in China. The key findings on the theory and practice of urban traffic planning systems will be presented and compared to the approaches in Europe. The comparison covers goals, achievements, regulations, sources and methods of data analyses and AI as well as shortcomings and potential improvements on both sides.

4 - Effect of CSR dimensions on organizational identification: Cultural implications
Semra Ascigil

Semra F. ASCIGIL and Burhan KAYA Middle East Technical University, Ankara

This paper aims to identify the impact of corporate social responsibility (CSR) dimensions on organizational identification by employees. Smith et al. (2001) viewed perceptions on four categories as a reliable way of studying CSR's relation with various variables. CSR policies affect the role played by a company in a community. CSR policies are the source for distinctiveness and prestige. Distinctiveness of an organization is found to be the predictor of organizational identity (Scherer & Palazzo, 2011). Employees, who are strongly identified with their organization, share the success and failure of the organization by becoming "psychologically connected" with the organization. Using Carroll's four corporate social responsibility dimensions i.e. economic, legal, ethical and discretionary responsibilities as a starting point, this paper first aims to identify the responsibility dimensions perceived by the sample in the current research, and then to examine the influence of these dimensions on organizational identification of employees. The factor analysis revealed three dimensions where legal and ethics related items merged under a single factor. Economic responsibility was not associated with organizational identification. Organizational identification was significantly affected by ethical/legal and philanthropy dimensions.

■ TA-27

Tuesday, 8:30-10:00 - F107

Dynamical Systems and Mathematical Modelling in OR 2

Stream: Dynamical Systems and Mathematical Modelling in OR
Invited session
Chair: *Burcu Gürbüz*
Chair: *Gerhard-Wilhelm Weber*

1 - Detectablility of weak links in the complex structure.
Krzysztof Szajowski

We analyze the possibility of assessing the availability of information about threats from elements of complex structures. The basis for the element assessment is the importance measures for multi-state systems introduced by Birnbaum (1969) and Barlow & Proshan (1975). The availability depends not only on reliability but also on the difficulty of maintenance, the ability to diagnose the need for service and its efficient implementation. If we assume that the need for maintenance is the result of deregulation, then determining the key elements to detect the moment of disorder of the system will be the basis for assessing the importance of the element for the system maintenance process.

R.E. Barlow and F. Proschan (1975), Importance of system components and fault tree event, Stoc. Proc. and Their Appl. 3, 153-172. Z.W. Birnbaum(1969), On the importance of different components in a multicomponent system, in: Multivariate Analysis II, ed. P.R. Krishnaiah (Acad. Press, NY), Part VII, p. 581-591. Fumio Ohi (2017) Importance measures of a component in a system. The 10th Int. Conf on Math. Meth. in Reliability, Grenoble, France, July 3-6, 2017. Krzysztof Szajowski (2016) Detecting the maintenance disruption in a competitive queue. W: Second International Symposium on Stochastic Models in Reliability Engineering, Life Science, and Operations Management, SMRLO Beer Sheva 2016, s. 274-283.

2 - Coordinated replenishment with demand and setup costs uncertainty
Laurence van Brandenburg, Dario Bauso

In supply chains coordinated replenishment of multiple items is a challenge when demand and setup costs are uncertain. This research proposes a continuous review multi-item two-layer inventory model. The main contribution is a novel approach to determine the "can-order" threshold and "must-order" point in a two-layer model under uncertain demand and uncertain setup costs. In this system, the first layer consists of pi-containers which ship items based on forecasted demand and the second layer involves the coordinated replenishment of the items. The research builds on the concept of "(S, c, s) policy" [1], which is extended to the case of uncertain setup costs (A, a). A case study is investigated which involves the sales of products in a network of interconnected cities. The cities are modelled as nodes in a graph and the edges are weighted by transport setup costs. The cities undergo demand in pi-containers and this constitutes the input to the first-layer. The first-layer includes demand forecasting models based on linear regression and exponential smoothing performed on historical setup costs and order data for each product. The experimental findings of the proposed model are discussed and ideas for future research directions are given.

Reference [1] Balintfy, J. (1964). On a basic class of multi-item inventory problems. Management Science 10(2), 287-297.

3 - Effects of Joint Negotiation in Procurement through a B2B Platform
Liming Liu

B2B procurement platform is an e-business model that enables small and medium downstream buyers to procure through forward contracts which are otherwise inaccessible for them individually. The key mechanism of this business model is that the upstream suppliers who hold significant market powers are now negotiating supplier contracts of large quantities efficiently with a single third party instead of numerous individual buyers whose procurement quantities are usually too small to make forward contract economically efficient/feasible. The recent boom of B2B procurement platforms has spread to diverse markets including fruits and agriculture products, construction materials, standard industrial material and components, and even some services, but not every well-run B2B platform is successful. This paper studies the effects of joint negotiation in B2B platform procurement from a risk management perspective. We construct a three-stage game model consisting of multiple downstream buyers, one upstream supplier, and the facilitating B2B platform. The multiple buyers, who belong to the same downstream product market, first decide whether to participate in the forward contract negotiation or to procure directly in the spot market. Given the number of participating buyers, an equilibrium forward procurement contract consisting of the contract price and quantities is negotiated between the supplier and the platform in stage 2. Finally, downstream product market demand is realized, spot

■ TA-28

Tuesday, 8:30-10:00 - G102

Risk Analysis and Management 2

Stream: Decision Making Modeling and Risk Assessment in the Financial Sector
Invited session
Chair: *Alessandro Staino*

1 - Optimal Mean-Variance Rules for Pairs Trading Strategy
Vladimír Holý

The idea behind pairs trading lies in taking an advantage of financial markets that are out of equilibrium. When some pairs of prices exhibit strong similarity in the long run and they are currently far enough from their equilibrium, traders might profit by taking a long position in one security and a short position in the other security. We assume the spread between securities to follow the Ornstein-Uhlenbeck process. Our goal is to find the entry signal, i.e. the level of spread at which we enter the trade, and the exit signal, i.e. the level of spread at which we exit the trade. Typically, this is done by utilizing first passage times of the Ornstein-Uhlenbeck process and maximizing the expected profit or Sharpe ratio. In our work, we adopt the mean-variance optimization related to the modern portfolio theory. Similarly to the case of maximizing the expected profit, we find that the optimal entry signal is symmetric to the optimal exit signal and the strategy simply suggests to switch positions when reaching the corresponding entry/exit signal. We illustrate the mean-variance pairs trading in an empirical study of 7 Big Oil companies traded on NYSE.

2 - An application of a weighted law of large numbers to portfolio credit risk

David Christen

A weighted version of a law of large numbers for sums of random variables with an underlying exchangeable structure is derived via the method of moments. In a first step, the method yields the moments of the limiting distribution. Conditions are given under which these moments correspond to the moments from the law of large numbers for equally weighted averages of exchangeable random variables where the moments can easily be evaluated. For all other cases, the computation of moments is numerically possible up to an order of around thirty. In a second step, an approach based on orthogonal polynomials is used to reconstruct the density function and/or distribution function of the limiting distribution from its moments. The method is then applied to portfolio credit risk.

3 - Portfolio selection models as a decision-making tool

Juraj Pekár, Ivan Brezina, Zuzana Čičková

Portfolio selection models are one of the tools that can be applied to determine the optimal portfolio composition according to the investor's investment profile (attitude towards risk). Optimization approaches orientated to portfolio selection strategy with objective to maximize revenue, minimize risk or maximize the portfolio performance are often used during investor decision making process. Formalized approaches in planning the allocation of financial assets and portfolio selection models are based on the approaches of mathematical programming and multiple criteria decision making. Nowadays, dynamic environment aspect is important in optimization of the portfolio, the ever-evolving system parameters such as market situations, military conflicts, etc.. Markov chains theory, which describes the transition between individual states using the vector of absolute probability states at the initial moment, and the matrix of conditional probabilities of transition between states, can serve as one of the tools. In the case of financial markets analysis, the multiple criteria decision making problems are described in the sets of variants, the set of evaluation criteria and the links between them are analysed.

4 - Do diamond stocks sparkle in investors' portfolios?

Rita D'Ecclesia, Vera Jotanovic

Diamonds are considered a new investment asset, providing great opportunities for trading, investing and diversification. Hedge funds and financial intermediaries have shown increased interest in the diamond market offering diamonds as a successful hedging tool. However, the lack of standardization and creation of a reference tradeable asset prevented the existence of an exchange regulated trading platform for diamonds. In a previous study D'Ecclesia and Jotanovic (2017) suggest the creation of a Standardized Diamond basket index which may represent a tradeable asset for investors. At the moment a possible alternative to the polished diamond market index may be represented by diamond producing companies which are listed on the major stock Exchanges. (Neil, 2014; Wilson and England, 2014). The aim of this paper is to verify if Diamond producing companies may provide a proxy for the diamond market. Using time series econometric models and an Asset pricing framework we investigate if diamond mining stocks' prices represent a robust proxy for diamond investments and if they do represent a hedge or safe haven. Our results show that the market of diamond stocks does not represent a valid investment alternative to the diamond commodity, and their dynamic is mainly driven by the stock market volatility.

■ TA-29

Tuesday, 8:30-10:00 - C118

Big Data I

Stream: Big Data in Complex Systems
Invited session
Chair: *Hiroyuki Kawano*

1 - Towards a Scalable Anomaly Detection with Pseudo-Optimal Hyperparameters

Jellis Vanhoeyveld, David Martens

Anomaly detection (AD) involves the detection of instances that deviate from normal behaviour. This seemingly simple task still poses two open issues that are addressed here (1) The specification of hyperparameter values for AD methods is a difficult task in the absence of labels. The community developed techniques are either too computationally involved and/or are tailored to a single type of AD method. Benchmarking studies therefore rely on an arbitrary parameter choice or adopt standard statistics (mean, max) to summarize the performances across a range of parameter settings. These methodologies are inappropriate and we develop a new pseudo-optimal parameter setting to tune the hyperparameters of any AD algorithm. Statistical tests reveal that this approach significantly outperforms a random choice. (2) Many AD techniques show high predictive performances yet are too computationally involved. We present the class of Fixed-Width Anomaly Detection (FWAD) methods that conducts a preliminary data compression with fixed-width clustering (FWC) and applies the original AD technique to the resulting cluster centres. FWC stores local density estimates that are valuable for the AD task. Our results indicate that FWAD is significantly faster than AD if the latter has a superlinear complexity in the number of instances N. For many AD types, no significant AUC differences are observed between FWAD and AD with pseudo-optimal hyperparameter settings.

2 - A New Bi-level C-GRASP Method to Solve Large-Scale Nonlinear Global Optimization Problems

João Lauro Faco', Ricardo Silva, Mauricio Resende

We address nonlinear optimization problems with nonlinear constraints where the numbers of n continuous bounded variables, and m nonlinear constraints are large, and n>m. Continuous-GRASP solves efficiently global optimization problems with bounded variables adapting the GRASP meta-heuristic procedure of Feo and Resende for discrete optimization problems. Here a new method with 2 levels is proposed to solve large-scale nonlinear optimization problems: (1) Optimization phasis: consider a feasible starting solution where we can fix m of n variables by a specific heuristics. A reduced problem in (n-m) independent variables can be solved by a C-GRASP method for bounded variables where the m nonlinear constraints are incorporated into the objective function by quadratic penalty terms. (2) Feasibility phasis: once a near optimal solution of the reduced problem is obtained, we verify the m basic variables feasibility by solving a system of m nonlinear equations by a 2nd level C-GRASP keeping fixed the (n-m) independent variables. If a basic variable violates any bound we do a change-of-basis; repeat (1), (2) until a stop rule is satisfied and a feasible global optimal solution has been attained.

3 - Privacy-Preserving Data Mining Algorithms for Distributed Database

Hiroyuki Kawano

At present, data mining are widely applied to various databases, in particular, we focus on practical applications using privacy-preserving data mining algorithms. In previous researches, we proposed one of applications, such as "cloud architecture of traffic mining systems under privacy preservation," and evaluated encripted computing cost on our prototype cloud system based on a combination of CMS and HElib, which is a fully homomorphic encryption library in C++ and the NTL mathematical library. Currently, it is becoming important to execute popular data mining algorithms for encrypted databases under privacy preserving conditions, and to discover rules from combinations of different data resources. In this presentation, firstly we propose an architecture of distributed databases for data mining applications.

We try to evaluate computing cost of privacy data mining in our proposed data mining system. Secondly, in order to decrease the mining computational cost, we focus on faster algorithms, which are proposed and developed by several researchers. Finally, we estimate computational cost of privacy-preserving data mining algorthms for distributed databases.

■ TA-30

Tuesday, 8:30-10:00 - C007

Graphs, Data and Optimization

Stream: Data Science Meets Optimization
Invited session
Chair: Pieter Leyman

1 - A Comparison of Models for Uncertain Network Design
Francis Garuba, Marc Goerigk, Peter Jacko

To solve a real-world problem, the modeler usually needs to make a trade-off between model complexity and usefulness. This is also true for robust optimization, where a wide range of models for uncertainty, so-called uncertainty sets, have been proposed. However, while these sets have been mainly studied from a theoretical perspective, there is little research comparing different sets regarding their usefulness for a real-world problem. In this paper we consider a network design problem in a telecommunications context. We need to invest into the infrastructure, such that there is sufficient capacity for future demand which is not known with certainty. There is a penalty for an unsatisfied realized demand, which needs to be outsourced. We consider three approaches to model demand: using a discrete uncertainty set, using a polyhedral uncertainty set, and using the mean of a per-commodity fitted zero-inflated uniform distribution. While the first two models are used as part of a robust optimization setting, the last model represents a simple stochastic optimization setting. We compare these approaches on an efficiency frontier real-world data taken from the online library SNDlib and observe that, contrary to current research trends, robust optimization using the polyhedral uncertainty set may result in less efficient solutions.

2 - Community Detection based on Graph Neural Network
ChulHee Lee, Dohyun (Norman) Kim, Taeho Kim

Communities in social networks are the dense subgroups of the nodes, which are tightly connected to each other within the group. Detecting communities is one of the important tasks in social network analysis because communities play key roles in understanding the functionality of complex networks. For example, communities in citation networks correspond to the group of articles with similar topics. Communities in the protein interaction network represent proteins with similar functionality. Recently, many deep learning algorithms to detect communities in social networks have been studied due to their robust performance. However, existing deep learning based community detection methods mostly have used deep learning algorithms only to find hidden feature vectors of nodes and then employed clustering algorithms on the extracted feature vectors. In this paper, we propose a unified community detection method combining hidden feature extraction and clustering algorithms. The proposed method combines Graph Auto-Encoder (GAE) and Deep Embedding Clustering (DEC) in social networks. The proposed approach is compared with various community detection methods. Experimental results show the proposed approach can be used as a useful alternative for community detection.

3 - The Intermittent Traveling Salesman Problem: How Can We Properly Combine Solution Representation and Local Search into a Metaheuristic Algorithm?
Pieter Leyman, Patrick De Causmaecker

We consider the intermittent traveling salesman problem (ITSP), an extension to the well-known traveling salesman problem, which adds a required processing time at each node. The allowable consecutive process time for a node is, however, limited, which results in nodes having waiting time and/or multiple visits. First, we omit assumptions made in earlier work on the ITSP, to allow for a broader and more realistic discussion of the problem. Second, we propose a metaheuristic algorithm for this extended ITSP. We distinguish between several options for the decoding procedure from solution representation to actual ITSP tour. This includes but is not limited to a simple solution representation combined with a local search-heavy decoder, and a more intricate representation which only requires some straightforward repair operators. Furthermore, self-adaptive operators are introduced to evaluate the impact of providing more intelligence to the overarching metaheuristic. Third, we integrate our algorithm within a metaheuristic development framework, which aims to provide meaningful insights into the performance of each of the algorithm's components. In terms of data, one of the crucial aspects is to generate problem instances which allow for a sufficiently diverse evaluation of the instance space.

■ TA-31

Tuesday, 8:30-10:00 - G108

Simulation for diagnostic pathways

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Emma Aspland

1 - Using Discrete Event Simulation in Radiology to model resource utilisation, delays and distractions - a radiographer's experience
Mary Conlon

Radiographers combine technical excellence, clinical decision making and patient care to produce diagnostic images and reports that contribute to the management of the patient. Demand for diagnostic imaging services is increasing year on year. Ireland has a growing and ageing population and demands for diagnostic imaging services are increasing. Radiology workload, when defined in crude numbers of examinations completed, fails to capture staff workload and patient complexity. This empirical work examines the use of operational research techniques, as communication and modelling tools. This paper details the discrete event simulation (DES) modelling of CT (Computed Tomography) services in a diagnostic imaging department. The validated simulation provides a decision support tool for managers and policy makers. The model includes a careful study of radiology data pertaining to service demand and patient complexity. This paper describes ongoing research investigating how simulation can facilitate data driven change of work practices and policies, allowing for better utilisation of limited resources. The challenges associated with modelling are considered. All modelling should be mindful of staff workload taking into consideration interruptions, complications and patient complexity to avoid unintended consequences such as burnout and poor patient care.

2 - Using simulation modelling to improve mental health system planning
Richard Guerrero-Ludueña

Despite WHO recognising mental health (MH) as an integral part of health and well-being, the burden of mental disorders continues to grow, affecting one in four people in the world at some point in their lives. NHS England is aiming to transform MH services by 2020, with an ambition of placing MH on equal terms to physical health.

A recent systematic review of simulation modelling in MH shows that the application of simulation in health system planning and optimisation is relatively underrepresented in comparison to areas such as medical decision making and epidemiology.

This paper describes the application of simulation modelling for testing different configurations in a regional MH system in the UK. The study focused on the analysis of current activity, estimation of future demand, and capacity of the MH system under different potential scenarios.

3 - Demand and Capacity Modelling for Cancer Pathway Diagnostics in Wales
Paul Harper, Geraint Palmer

Vaughan Gething, the Cabinet Secretary for Health and Social Services in Wales, announced his intention to adopt a new single cancer pathway in Wales. Though the new pathway had the full support of the clinical community, concerns remained regarding the impact on diagnostic capacity within secondary care. Using data from a pilot study, this talk will describe development and use of a demand and capacity model, utilising queueing theory and computer simulation, to calculate the impact on cancer diagnostic tests against a range of delivery parameters. As such, it was the first comprehensive study in Wales to both assess current diagnostic waiting times across all cancers, and to provide recommendations to Public Health Wales and the Cabinet Secretary on the necessary capacities and pathways in order to meet Welsh Government diagnostic waiting time targets.

4 - Modelling Lung Cancer Clinical Pathways
Emma Aspland, Paul Harper, Daniel Gartner

Clinical pathways are an effective and efficient approach in standardising the progression of treatment to support patient care and facilitate clinical decision making. Our review of the related literature highlighted a need to better integrate data engineering and OR techniques with expert/domain knowledge to assist with clinical pathway discovery and formation. Consequently, we have produced a decision support tool that facilitates expert interaction with data mining, through the application of clustering. This has involved the development of a new distance metric, modified from the Needleman-Wunsch algorithm, that considers weightings and groupings of activities as specified by an expert user. The resulting set of pathways are then automatically translated into the basis of a discrete event simulation to model patient flows through the captured clinical pathways.

Our research is in partnership with Velindre Cancer Centre, the largest specialist cancer centre in Wales, and has the overall goal to improve patient care and outcomes by reducing time to diagnosis and treatment for those with lung cancer.

■ TA-32

Tuesday, 8:30-10:00 - G109

Biological Networks

Stream: OR in Life Sciences
Invited session
Chair: *Vilda Purutcuoglu*
Chair: *Harshita Kajaria*
Chair: *Lidia Betcheva*

1 - Investigation of the OWL-based Biomedical Ontology with the Social Network Analysis
Martina Husáková

Semantic web ontologies are network-based structures generally used for information and knowledge modelling of specific application domain. This representation assists with machine processing of facts included in an ontology and ease communication between machines for needs of end users. The ontologies can be analysed in a view of their structure and semantics. This contribution is focused on the first view where concepts of social network analysis are applied for exploration of the ontological structure. Social network analysis provides qualitative and quantitative approach for uncovering often hidden information or knowledge. It operates with nodes representing living or non-living entities and links (relationships) existing between these entities. Ontologies represent the same "things", but different terminology is used. SPARQL query language and Python scripting language is applied for practical application of social network analysis concepts for structural analysis of the ontology modelling specific autoimmune diseases. The main motivation behind this study is to better understand the ontological structure and to provide richer metadata, because majority of bioportals accessing of biomedical ontologies provide often only the most fundamental facts about structures of these ontologies. Social network analysis can provide deeper insight into these ontological structures.

Support of the Czech Science Foundation GAČR 18-01246S is gratefully acknowledged.

2 - Novel Magnetic Coils placement and Setting Schemes in Micro/NanoBots Networks
Hong-Hsu Yen

Micro/NanoBOTs (MNBOTs) which emerged in recent years is a new technology where the nodes are with size of micrometer to nanometer scale. It enables much wider human medical applications via implanting MNBOT into the human's body for high precision medical applications. In this paper, we study and propose MNBOT network deployment problems in cancer treatment applications. In this MNBOT network deployment problem, magnetic coils placement is tackled where the objective is to minimize the magnetic coils deployment cost so as to guide the MNBOTs to the target sites. The constraints include covering the tumor cells with attractive magnetic potentials and covering the normal cells with repulsive magnetic potentials. Besides the magnetic guiding force, the MNBOT movement intervention from Brownian motion is also studied to determine the best magnetic coils placement strategy. We propose an optimization-based mathematical formulation and heuristics to catch the interplay of magnetic field settings and MNBOT routing decisions. To the best of our knowledge, this paper will be the first one to address controlling a swarm of MNBOTs via magnetic field settings for high precision bio-medical applications. With this new developed magnetic MNBOT networks, it sheds another promising solution to the diseases that is inaccessible by conventional medical procedures (e.g., cancer treatment).

3 - Which stage of the industry lifecycle do Clinical Research Organizations (CROs) currently reside in? An exploratory analysis using clinical trials data
Lidia Betcheva, Feryal Erhun

Emerged in the 1980s, clinical research organizations (CROs) have since flourished into a multibillion-dollar industry and have become vital for biopharmaceutical R&D. Recently, we have started to observe the indicative signs of maturation in the CRO industry. Yet, analysts have offered various outlooks regarding the industry's future and it is not clear whether the industry is still growing, has reached maturity or is in a state of decline. Applying Bass diffusion methodology on an extensive dataset assembled from the AACT (Aggregate Analysis of ClinicalTrials.gov) database and other publicly available data, we aim to answer the following: Which stage of the industry lifecycle do CROs currently reside in? We further study the dynamics of CRO adoption (i) in different phases of clinical development and (ii) by various clients. We provide empirical evidence indicating that the industry has reached maturity; we predict that the average growth in cumulative CRO adoption will drop significantly over the next five years. We forecast a declining growth in cumulative CRO adoption for all phases (1-4), with the smallest drop for phase 1 trials. Furthermore, a decrease in the rate of adoption by hospitals, medical device manufacturers and institutes provides evidence that there is limited opportunity for CRO adoption in studies which evaluate non-drug interventions such as medical devices. Our results carry important capacity and capability planning implications for CRO managers.

■ TA-33

Tuesday, 8:30-10:00 - Q005

Economic modelling and game theory II

Stream: Dynamics and Games
Invited session
Chair: Eleonora Fendekova

1 - Technology Improvement Contracting in Supply Chains under Asymmetric Bargaining Power

Ali Shantia, Sam Aflaki, Andrea Masini

Evidence shows that suppliers refrain from investing in technology improvement (TI) measures because they fear that a buyer with greater bargaining power will use TI-related cost reductions to push prices down—in the purchase bargaining process—and thereby further reduce the supplier's profit margin; this dynamic leads to inefficient levels of investment in TI and leads to the so-called holdup problem. Suppliers are also discouraged from TI investment by the uncertainty associated with new technologies. These two issues are studied via our model of the bargaining process, in a two-tier supply chain, between a single supplier and buyer; we analyze how the supplier's TI technology adoption is affected by the buyer's relative bargaining power and also by technology uncertainty. We compare various contracting arrangements commonly used in industry to overcome these obstacles, including price commitment by the buyer and shared investment contracts, while characterizing their optimal properties with respect to different criteria—in particular, supply chain profit and the equilibrium level of TI investment. In terms of both criteria, we find that shared investment contracts perform better than price commitment contracts, although the latter increase supplier profit when the buyer's bargaining power is relatively high. We also show that, in a two-player model, technology uncertainty moderates how the bargaining process affects the supplier's investment behavior.

2 - Financing investments in supply chains: a game-oriented collaborative supply chain finance model

Carolyn Somorowsky, Hans-Dietrich Haasis

Competitive advantage is achieved not by a single company but rather by the whole supply chain, focusing on the improvement of the information flow, the financial flow, and the flow of goods. For improving these flows, strategic relevant or relationship-specific investments needs to be done, which not uncommonly have a long-term character, are capital intensive and risky. With the financial crisis banks become more risk averse, whereby financing high-risk investments becomes expensive or it is even difficult to obtain funding from external financial institutions. Supply Chain Finance is a young discipline that deals with the improvement of the financial flows referring to a collaborative approach. As most strategic investments are made by suppliers facing a financial gab, supply chain disruptions are most likely to occur, due to bankruptcy of the financing party or lack of investment. In order to enhance strategic investments and avoid supply chain disruptions a Collaborative Supply Chain Finance model is developed, where members of the supply chain use their internal funds to realize these investments and share cost, risk, and benefits according to their contribution. The suggested model is based on a cooperative game with transferable utility and determines a coalition that is best of financing the investments without deteriorating the financial stability of the coalition members.

3 - Medical Items Inventory Sharing Strategy Between Two Hospitals

King-Wah Anthony Pang, Ping Zhang, Hong Yan

Inventory management of medical supplies in a hospital is critical to patients who receive healthcare service. When urgent situations happen, e.g., natural disasters, massive traffic accidents or infectious disease outbreaks, demand for rescue medical items increase drastically. The stocks in the hospital might not be enough to cater to this sudden demand. Placing expensive emergent replenishment order to the dealer is the only approach to satisfy the demand to save the patients' life. In fact, another hospital nearby might have excessive stocks which could be shared with this hospital so as to save time and cost. Therefore, this paper proposes an inventory sharing mechanism for disposable medical items between two independent hospitals. We explore the value of a single-item sharing policy in a two-period setting. We first identify the emergent replenishment policy and related inventory decisions when hospitals are under no sharing scenario. Then we suggest a safety complete sharing policy between two hospitals and derive the optimal inventory decision for each hospital. Furthermore, we investigate the effect of emergent request rate of patients, the safety inventory level of hospital and other cost parameters on optimal inventory decision. Through numerical experiments, we find that inventory sharing is more economical than emergent replenishment policy. We also find that under sharing policy, the increase of partner hospital's emergent request rate and safety in

4 - Models of Regulation as a Tool for Risk Elimination in Network Industry Markets in Slovakia

Eleonora Fendekova, Michal Fendek

Currently a significant attention in scholarly discussions on various levels is being paid to the subject of network industries. It is understandable as network industries in fact ensure the production and distribution of energy sources that play a key role in an effective operation of the developed economies. The discussions are usually focused on the question of a reasonable profit of the network industries companies and on the other hand on the question of regulated prices which are determined by the reasonable profit and generally acceptable costs of their production. In Slovak conditions, Regulatory Office of the Slovak Republic represents a role of the regulator for Network Industries, which role is to issue licenses, regulate prices and quality norms for network industry products. The aim of the paper is to examine the equilibrium conditions in the market of network industries. The stress will be laid on regulation on the base of returns and on the price regulation on the basis Averch-Johnson model. Attention will be paid to the ways of calculation reasonable profit in regulated industries and assessment of effectiveness and influence of regulation measurements on network industries. This issue bears an increased attention under conditions of economic influence of network industries in the national economies since the second half of the twenties of the last century. This tendency is especially visible particularly in the context of economic globalization.

■ TA-34

Tuesday, 8:30-10:00 - Q006

Fuzzy Methods in MCDA

Stream: Multiple Criteria Decision Making and Optimization (contributed)
Contributed session
Chair: Tadeusz Antczak

1 - Constructing Research Topic Maps for Air Pollution Researches by Text Mining and Multiple Rule Decision Making Methods

Chi-Yo Huang, Chia-Lee Yang, Ching-Chun Hsu, Hsing-Yen Ann

During the past decades, air pollutions are becoming one of the most concerned issues in most economies due to the significant influences of the contaminations to the life and health of human beings. Therefore, researchers are paying more attentions to air pollutions and the corresponding effects. Derivations and analysis of research topic maps can help identify new opportunities for researchers. However, very few scholars tried to introduce the research topic maps on the study of air pollution related issues. Therefore, this study aims to introduce the research topic map to analyze the trends regarding to air pollution studies. The Microsoft Academic Graph dataset will first be mined to derive publications and keywords related to air pollutions. The top keywords will be extracted. Then, each keyword will serve as the decision variable (or the consequent) while the rest keywords will serve as the conditional variables. The Dominance Based Rough Set Approach (DRSA) will be adopted to derive the "if . . . then . . . " inference relationships. After that, the decision-making trial and evaluation laboratory (DEMATEL) technique will be used to derive the cause-effect relationships among the topics. Then, the inference relationships will be introduced into the DEMATEL, where the antecedents will serve as the causes and the consequents will serve as the effects. The research topic map being derived can serve as the basis for future researches.

2 - Multi-Attribute Decision Making and Hesitant Fuzzy Sets - An integrated approach for product recommendation in the online business
Bhaba Mohanty

This paper introduces a methodology based on hesitant fuzzy sets to recommend a product on the online business when the products are evaluated through multiple attributes. The buyers' confusion in the evaluation of product with respect to its attributes, in single precise terms and his/her hesitation in a range of values are handled using hesitant fuzzy sets. Our paper takes the buyers' attribute wise evaluations of the products as hesitant fuzzy values. The credibility of an attribute is derived by measuring how far its evaluation with respect to the products is superior to that of another attribute according to the buyers' perception. This is done using the concepts of priority degrees for hesitant fuzzy sets. Repeating this process across the attributes, we obtain the best attribute corresponding to the maximum credibility and the worst attribute that attributes to the minimum credibility. The multiplicative preference comparison matrix that compares how an attribute is better than the other attributes by using the credibility indices. The work compares best attribute with the other attributes and the other attributes with the worst attribute. The comparison gives us a non-linear programming problem and the solution therein gives the attribute-weights. The product value of a product is the weighted aggregation of the product attributes. The product with maximum product value is recommended to the buyer in the e-business.

3 - The l1 exact penalty function method for solving nondifferentiable fuzzy optimization problems
Tadeusz Antczak

For many mathematical programming models of real world problems, it is usually difficult to determine the coefficients of the involved functions as real numbers since, most often, these possess inherent uncertainty and/or inaccuracy. Given that this is the usual state, fuzzy optimization is considered as one approach to tackle uncertainty and inaccuracies in the coefficients of the functions constituting optimization models. Our considerations are devoted to investigate the most popular nondifferentiable l1 exact penalty function method when it is used for solving nondifferentiable optimization problems with fuzzy objective functions. It is analyzed the most important property of this exact penalty function method, that is, exactness of the penalization, in the case when this method is used for solving such nonsmooth extremum problems. It is proved that any (strong) KKT point of the considered fuzzy optimization problem is a (weakly) nondominated solution of its associated fuzzy penalized optimization problem constructed in the used approach. Also the conditions are derived under which there is the equivalence between (weakly) nondominated solutions of these fuzzy optimization problems. Further, the convergence of the algorithm of the l1 exact penalty function method is also established in the case when it is used for solving a nondifferentiable fuzzy optimization problem with fuzzy objective function and inequality constraints.

■ TA-35

Tuesday, 8:30-10:00 - Q009

Game Theory, Solutions and Structures II

Stream: Game Theory, Solutions and Structures
Invited session
Chair: Peter Sudhölter

1 - The procedural egalitarian solution and egalitarian stable games
Bas Dietzenbacher

This paper studies the procedural egalitarian solution on the class of egalitarian stable games. By deriving several axiomatic characterizations involving consistency and monotonicity, we show that the procedural egalitarian solution satisfies various desirable properties and unites many egalitarian concepts defined in the literature. Moreover, we illustrate the computational implications of these characterizations and relate the class of egalitarian stable games to other well-known classes.

2 - Dimensionality of Simple Games
Xavier Molinero, Fabián Riquelme, Salvador Roura, Maria Serna

A simple game is a kind of cooperative games formed by a finite set of players and a monotonic family of subsets from the considered players. A simple game is a weighted voting game if there is an integer quota and an assignment of a non-negative integer weight to each player so that a coalition is winning if and only if the sum of the weights of its players is greater than or equal to the quota. It is known that each simple game can be expressed as the intersection (or the union) of weighted voting games. Two essential concepts well known over simple games are the dimension and the codimension. The dimension (codimension) is the minimum number of weighted games such that their intersections (unions) generate the considered simple game. There are previous studies about the dimension and the codimension of simple games. For instance, some authors have studied the maximum dimension or codimension that can be achieved with a specific number of players. In this work, we present a complete classification about the (codimension) dimension of simple games with a specific number of players. We also introduce the concept of multidimension. Moreover, we compute the exact dimension, codimension or multidimension for some simple games with special properties. Finally, we also present some related open problems.

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3 - Egalitarianism in surplus-sharing problems and the Dutta-Ray solution
Peter Sudhölter, Pedro Calleja, Francesc Llerena

The constrained egalitarian surplus-sharing rule divides the surplus so that the poorer players' resulting payoffs become equal, but not larger than any remaining player's status-quo payoff. We show that this rule is characterized by Pareto optimality, path independence, requiring that the assigned shares remain unchanged when applying the rule consecutively to any partition of the surplus, and less first (LF), requiring that a player does not gain if her status-quo payoff exceeds that of another player by at least the surplus. We use this result to show that on the domain of convex games Dutta-Ray's egalitarian solution is characterized by aggregate monotonicity (AM), requiring that no player suffers if the grand coalition becomes richer, bounded pairwise fairness, resembling LF, and the bilateral reduced game property (2-RGP) à la Davis and Maschler. We also show that 2-RGP can be replaced by individual rationality and bilateral consistency à la Hart and Mas-Colell. Finally, we prove that the egalitarian solution is the unique core selection that satisfies AM and constrained equal treatment (CET), requiring that the poorest players cannot be made richer without assigning to the complement less than its worth. Strengthening CET by replacing "poorest" by "poorer" allows to eliminate AM. The results using consistency axioms require the domain of convex games with players in a universe of size 3, whereas the other characterizations work for a fixed player set.

■ TA-37

Tuesday, 8:30-10:00 - Q011

Scheduling with Resource Constraints: Project Scheduling

Stream: Scheduling with Resource Constraints
Invited session
Chair: *Viktoria Hauder*
Chair: *Isac Mendes Lacerda*

1 - Solving a new bi-objective flexible resource-constrained multi-project scheduling problem
Viktoria Hauder, Andreas Beham, Sebastian Raggl, Michael Affenzeller

Multiple conflicting objectives are very often part of real-world decision situations. One example is the production process of a steel manufacturer where the well-known divergent goals of time minimization and quality maximization have to be evaluated. In this work, such a manufacturing process is modeled as a new bi-objective flexible resource-constrained multi-project scheduling problem (BI-FRCMPSP). Multiple lots (=sub-projects) have to be produced simultaneously and flexible processing times (minimum and maximum allowed processing time per activity) have to be determined. Moreover, it has to be decided on one out of multiple alternative production routes for every steel lot. For every alternative route, a different quality-related priority is prescribed by the manufacturer. The popular objective of makespan minimization and the newly developed objective of quality-related priority maximization are then taken into account. In order to give the human operators a preselection of possible well-balanced solutions, the goal of this work is to provide all existing non-dominated points of this new problem. The well-known epsilon-constraint method is applied by developing and comparing new MIP and constraint programming (CP) models.

2 - Multi-Mode Resources-Constrained Scheduling Project Problem with both cumulative and disjunctive constraints under uncertainty
Lucas Groleaz, Christine Solnon, Samba Ndojh Ndiaye

We consider a real industrial problem which is a special case of the Multi-Mode Resource-Constrained Project Scheduling Problem (M-RCPSP) with both cumulative and disjunctive resources. Activities have due dates and our objective is to minimize the sum of tardiness over all the activities. Moreover some activities are not known at the beginning of the schedule and will only be revealed during execution. Nevertheless we have at disposal historic data which allow us to make some statistics on events which can occur. Hence our purpose is to evaluate both interest and feasibility of exploiting historic data by tackling the problem in three different ways: static, online and stochastic. In the static case all the activities are known beforehand. In the online one activities are revealed during the execution of the algorithm. The stochastic case is identical to the online one, but we additionally use the probabilistic knowledge we have to get better solutions. For the static case we compare several meta-heuristics, including simulated annealing, tabu search, and ant colony optimization. We use the same meta-heuristics for the online case, but we consider only the activities already revealed, and we forbid reallocation of activities that have already begun. For the stochastic case we compare several variants of the One-Step Anticipatory Algorithm : Expectation, Consensus and Regret.

3 - Optimizing control limits on activity duration with respect to project's overall cost
Ken-ichi Suzuki, Tetsuo Iida

A control chart is a common tool for monitoring various aspects of a project. By measuring the observations of activities' behavior, a project manager (PM) can detect anomalies in cost and schedule. Moreover, she/he can take further actions if an observed value exceeds the control limits. Typically, the alpha-percentile of the distribution of the monitoring variable is employed as a value of the control limits. Alpha, say 90% or 95%, reflects the risk tolerance of the PM. This approach may work well pragmatically, although it has two main drawbacks. First, each activity contributes differently to the project duration. Hence, instead of using an identical percentile, the PM should consider each individual activity's relative importance to the project. Second, the conventional approach lacks a cost perspective. Since the control limits affect the cost of corrective actions, the PM should evaluate their impact on the total budget to determine the control limits. These points of view suggest a new approach within which the control limits can be optimized with respect to both cost and schedule. In this presentation, we will propose an integral framework to select the optimal control limits as well as the optimal resource allocation. The model is formulated as a two-stage stochastic programming problem that includes decision variables corresponding to activities' control limits in the first stage. We will also discuss heuristic approaches to simplify the computational process.

4 - Analysis of the Polynomial Complexity of a Classic Algorithm for a Project Scheduling Problem with the Maximization of the Net Present Value
Isac Mendes Lacerda, Jayme Szwarcfiter, Eber A. Schmitz, Rosiane deFreitas

Among the project scheduling problems is the maximization of Net Present Value (NPV) without resources constrained, with finish-start precedence and 0-lag between activities. For this problem, Demeulemeester and Herroelen (2002) proposed an algorithm organized in three steps. In the first step, a tree called Early Tree (ET) is created with as soon as possible scheduling for each activity, respecting the precedences (memorized in a graph). In the second, it generates a copy of the ET, called Current Tree (CT) to identify negative activities without successors are identified. In the third, the algorithm identifies and postpones sets of activities that can increase NPV. To do this, it dynamically creates and deletes precedences in the CT. The first and second steps happen in O(n2) time complexity, given by the authors. However, the third and most important step was considered an open question. Thus, in this work, we present the analysis of the computational complexity to this algorithm, where the worst case occurs in an arrangement with sequential activities, where requires the maximum of disconnections and connections of activities. This condition and step also configures an O(n2) time complexity. Such characterization confirms the robustness of the solution proposed by the authors, as well as contributes to other related algorithms and work researches. Ref.: Demeulemeester E., Herroelen W. 2002. Int.Series. Project scheduling — A research handbook. Boston: K. Academic.

■ TA-38

Tuesday, 8:30-10:00 - Q012

Decision Aiding Methods 2

Stream: Multiple Criteria Decision Aid
Invited session
Chair: *Maria Cerreta*

1 - Risk analysis and management for urban planning decisions: a decision aid perspective
Francesca Torrieri, Alessandra Oppio, Marta DellOvo, Emanuele DellOca

Urban developments are complex processes characterized by the presence of several actors willing to act with the aim of optimal levels of both return and risk. The trade-off between risk and profit represents a key factor in investment decisions, even more in the case of urban developments characterized by public-private partnerships and long-term horizons. Two different perspectives on risk management, a traditional engineering and a behavioural perspective. The behavioural perspective seems very promising to get more insight in the actual risk behaviour of developers, but an adequate framework is lacking. Considering these premises, the work will be focused on the relation between profit and risk in urban development projects under the perspective of finding a balanced allocation of risks. For this purpose, we have proposed a multidimensional and multistakeholder approach for risk analysis and management. A questionnaire has been administered to a panel of expert in order to rate the risk perceived by actors involved in real estate development and how it changes according to the role they play in each stage of the process.

2 - Evaluating the environmental quality of a territorial system taking into account interaction of criteria through the Choquet integral preference model
Marta Bottero, Chiara D'Alpaos, José Rui Figueira, Salvatore Greco

Environmental quality is a complex multi-faceted concept which refers to a set of environmental characteristics and properties. In order to measure it several variables and indicators have to be taken into account: air pollution, waste management, soil consumption, acoustic emissions, etc. Moreover, the natural dynamics of land-use territorial systems are often characterized by interactions among environmental and ecological components, thus requiring the adoption of specific valuation approaches. This paper presents an application of the Choquet multiple criteria preference aggregation model proposed by Bottero et al. (2018) for measuring the environmental quality of a set of 20 municipalities located in a semi-rural area in Piedmont Region (Italy). According to Bottero et al. (2018), in order to apply the Choquet integral approach to a real world decision problem, two procedures will be implemented: the first is used to assign utility values on a common scale to criteria performances, and the second to assign numerical values to the capacities of the Choquet integral. In detail, we provide a scoring of the municipalities under investigation based on a set of multidimensional indicators that can be useful in the assessment of overall environmental conditions and in supporting strategic planning decisions. To structure the valuation model we organized focus group with multidisciplinary experts in landscape planning and management, ecology and socio-economic systems.

3 - An integrated decision support tool to evaluate retrofit scenarios at district scale
Federico Dell'Anna, Cristina Becchio, Marta Bottero, Stefano Corgnati, Giulia Pederiva, Giulia Vergerio

In recent years, a new sustainable view of urban settlement is rising. Indeed, the European Commission defines the post-carbon city as characterized by buildings consuming low energy due to smart heating and cooling systems, and sustainable transport solutions based on the use of private electric and hybrid vehicles. In this context, new parameters come into play with the aim of identifying the best design profile to respond to new energy, environmental and market policies. In accordance with the European Directive, the tool used when evaluating public projects and policies is the Cost Benefits Analysis (CBA). It has been highlighted that one of the main limitations of the CBA method is the estimation of all positive and negative externalities in monetary value. To overcome this obstacle, a growing scientific literature on the application of Multi-Criteria Analyses (MCA) in the context of energy investments is emerging. In this work, the COSIMA (COmpoCIte Modelling Assessment) model (Barford et al., 2011), that combines the CBA and MCA methods, is proposed for ranking alternative retrofit scenarios for a district located in Turin (Italy). The integrated evaluation extends the conventional CBA into a more comprehensive evaluation, including decision criteria that would otherwise not be considered. A panel of actors has been involved to weight the effects and experts in energy have been consulted for discussing and validating the results.

4 - Assessing Urban Vulnerability: The potentials of Multi-Criteria Spatial Decision Support Systems
Maria Cerreta, Chiara Mazzarella, Giuliano Poli, Stefania Regalbuto

The contribution aims at structuring Spatial Decision Support System (SDSS) for vulnerability analysis of complex urban systems through multi-criteria procedures and multi-group methods within the Geographic Information System (GIS) environment. The heatwave hazard has been addressed focusing on the physical and social dimensions of vulnerability as a complex phenomenon requiring effective indicators which allow an adequate assessment in quantitative and qualitative terms. The different definitions of vulnerability and multiple impacts affecting the urban system led to developing two main models within a MCDA framework. The knowledge model allowed analysing of the features of the examined system and, concurrently, structuring of indicators dataset as a proxy of the spatial criteria. The evaluation model aims at a weighting of the normalized indicators with multi-criteria procedures and scoring them according to the preference of the experts. The spatial assessment of homogeneous vulnerability classes aided in transforming spatial indicators' values into clusters of priority. The achieved outcome is twofold since it concerns mapping and clustering of geographical zones which are more exposed to heatwave hazard in order to improve the spatial decision-making. The SDSS has been tested to the urban system which includes the eastern neighbourhoods of Naples city, in Southern Italy.

■ TA-39

Tuesday, 8:30-10:00 - Q014

Project Risk Management

Stream: Project Management and Scheduling
Invited session
Chair: *Mario Vanhoucke*
Chair: *Jeroen Burgelman*

1 - Improving the activity selection process for corrective action taking during project control
Annelies Martens, Mario Vanhoucke

Project control entails monitoring the progress of projects to detect deviations from the baseline schedule and, if necessary, taking corrective actions to get the project back on track. The corrective action taking process consists of several decisions, e.g. deciding which activities are eligible to take corrective actions on and which of the eligible activities should be selected to take corrective actions on.

In this study, the impact of these decisions on the final project duration and project cost will be examined. In particular, in order to review the impact of deciding the eligible activities, an interventive approach (i.e., focusing on activities in progress) will be compared to a preventive approach (i.e., focusing on future activities). Further, to select the actual activities that will be taken corrective actions on, a novel approach is proposed that estimates the project duration distribution before and after corrective actions to determine the activities with the highest expected impact on the project outcome. Finally, rather than assuming that the effect of corrective actions is deterministic, the impact of corrective actions on the activity duration and cost will be considered to be uncertain. Ultimately, the results of this study support the project manager in taking the most effective corrective actions with the highest impact on the final project duration and cost.

2 - An optimization method for budget allocation in risk prevention and protection
Xin Guan, Yao Zhang, Mario Vanhoucke

Project risk response is a critical issue in project management since project managers can take actions actively to cope with project risks in this phase. Most of the existing literature on project risk response focuses on determining response strategies to reduce the expected loss of risks. However, an effective risk response, in general, requires financial support, and an optimal budget allocation among risk response strategies can produce better risk response effects. This paper proposes a method that integrates fault tree analysis with a new optimization model to allocate a response budget from a preventive and protective perspective. The proposed method consists of three main steps. The first step is to analyze and calculate risk probabilities and risk losses which involve identifying risk causes that may trigger a risk event to occur using fault tree analysis. It also identifies consequences once the risk event occurs, evaluating the occurrence probabilities of risk causes and losses of consequences. The second step is to build a relationship between the budget allocated to risk response strategies and the corresponding response effects. The third step is to construct an optimization model aiming at minimizing the total risk cost. The 3-phases modeling approach aims at allocating the budget in an optimal way, and computational experiments will be discussed to present some managerial insights.

3 - The impact of control budget on the corrective action taking process
Jie Song, Annelies Martens, Mario Vanhoucke

Measuring the project performance of projects in progress is crucial in managing projects to generate warning signals that act as triggers for taking corrective actions to bring these projects back on track. The project manager has to decide whether the project performance is acceptable or not. To that purpose, tolerance limits are set on the required project performance, such that if the warning signals exceed these limits, they should result in appropriate corrective actions.

In this paper, we will make use of the Earned Value Management (EVM) control method, and test its ability to use it for taking corrective actions under a budget constraint. More precisely, we will propose five different approaches for allocating the limited budget along the different project phases, and measure whether a proper allocation of the budget results in an improvement in project outcome.

A large computational simulation experiment is conducted on a set of artificial projects to assess the efficiency and the effectiveness of the budget allocation models. Results show that simply allocating budget according to the time accrue of the project performs better than methods that incorporate cost or risk information. Moreover, results indicate that increasing the budget along the project progress outperforms decreasing budget constraints.

4 - Data Envelopment Analysis of project portfolios
Petr Fiala

Projects are in accelerating world rhythm the right option of solving problems of lot of organizations. Projects are the way for implementing the organization's strategy. Most project organizations exist in a multi-project environment. This environment creates the problems of project interdependency and the need to share resources. Project portfolio is set of all projects that are implemented in the organization at a time. The organisation has its total resources in limited quantities. Possible projects are characterized by sets of inputs and outputs, where inputs are resources for project realisation and outputs measure multiple objectives of the organisation. The Data Envelopment Analysis is an appropriate approach to select efficient projects. Designing a portfolio of efficient projects not exceeding the limited resources does not always lead to the most efficient portfolio. This paper aims to verify the ability to model and solve the problem of project portfolio using the Data Envelopment Analysis. Project portfolio management is a process. This process must improve over time. Building feedback into every stage of the process is critical for the improvement.

■ TA-40

Tuesday, 8:30-10:00 - Q015

Maritime Transportation II

Stream: Maritime Transportation
Invited session
Chair: *Benjamin Shelbourne*

1 - Charged by Terminal Operator or Ocean Carrier? About the Inbound Container Storage and Demurrage
Mingzhu Yu, Jan C. Fransoo, Chung-Yee Lee

In ocean transportation system, consignees are charged two kinds of fees for the inbound containers that are stored in the container terminal yard, namely, the demurrage fee and the storage fee. The demurrage fee is charged for the container occupation and the storage fee is charged for the yard space occupation. In practice, consignees are complaining about the charging of these two kinds of fees about the unclear fee collectors (sometimes consignees are charged by the container terminal operator exclusively, sometimes consignees are charged by the ocean carrier exclusively, while sometimes consignees are charged by both of them), and the unreasonable pricing.

In this paper, we study an inbound container pricing system including one maritime container terminal operator (MTO) and one ocean carrier. The MTO's decision is the storage fee, and the ocean carrier's decision is the demurrage fee. Through theoretical analysis we derive the pricing equilibria of the two players under three different charging modes: the carrier-charge mode, the MTO-charge mode, and the separate-charge mode. We find that the consignee's total payment and the two players' total profit are not affected by the charging modes. The MTO prefers to act as a follower who charges the consignee exclusively. While, the ocean carrier prefers to charge the consignee directly (no matter charging the consignee exclusively or charging with the MTO at the same time)

2 - A Two Dimensional Approach to Assessing the Port Choice Factors of Land-side Decision Makers using the Kano Model
Byung In Park, Chang Seong Ko

The implicit assumption of port choice studies is that the preference of the port choice attributes is proportional to the choice behavior. However, the port choice attributes of land-side decision makers may have non-linear properties. This study attempts to confirm the nonlinear characteristics of port choice attributes for land-side decision makers using the Kano model and develop a related strategy using importance-performance analysis. The findings show that the port choice properties of shippers and freight forwarders may have significantly different nonlinear factors and characteristic forms. The port service providers such as government, port authority, and terminal operating companies, have to develop and execute strategies or policies to improve performance based on the port selection factors of the shippers and freight forwarders; these factors are located in the one-dimensional characteristics of the Kano model and the concentrated improvement area of the importance-performance analysis. Therefore, the port choice service providers should develop and run a port operation strategy that reflects the characteristics of port choice factors of each land-side decision maker. Since this study aims at exploring the form of port choice characteristics of shippers and freight forwarders in a port, long-term additional verification studies on ports and stakeholders located domestically and abroad are required.

3 - Behind the Scenes: Research &Development for Singapore Next Generation Port
Chenhao Zhou, Ek Peng Chew

As the scale and complexity of container ports keep growing, more sophisticated, scientific and intelligent methods are required to support the planning and operation in next generation ports. As one of the world's top container ports, Singapore has put in place the Next Generation Port 2030 Initiative to continue delivering world-class services and retain its global leading position. As a part of Singapore maritime society, the Centre of Excellence in Modelling and Simulation for Next Generation Ports in the National University of Singapore has been established to help Singapore's maritime and port industries, develop innovative capabilities and enhance their global competitiveness. In this talk, we will introduce the core capability - how to integrate and implement simulation and optimization for the next generation ports, and share the latest research and development for the maritime and port industry, such as automated guided vehicle and autonomous truck related development, storage yard planning strategy, sea channel and berthing management, etc. Finally, we will share the future roadmap of the centre and Singapore maritime development.

4 - Transporting cargo for offshore wind farms using unmanned vessels: A selective vessel routing problem with due dates

Benjamin Shelbourne, Djamila Ouelhadj

This research introduces a new selective vessel routing problem with due dates, which arises in planning the delivery of maintenance cargo to offshore wind farms using unmanned vessels. Using the application terminology, each location that requires service will be described as a turbine. The problem is to select a subset of these turbines, and feasible routes for the vessels to service the chosen turbines. Each vessel has a fixed capacity, and must return to the depot by a given time; and each turbine has a load, due date, weight, and penalty, representing the vessel capacity consumed, the desired service time, a weight on tardiness, and a cost if the turbine is not serviced. The objective is to minimise a combination of the total transportation cost, the total weighted tardiness, and the total penalties. To explore the problem in the application context, we have generated a set of benchmark instances that consider a variety of wind farm scenarios and other problem variables. To solve these instances in acceptable computational time, we compare different search neighbourhoods, and present results from extending the best combination of neighbourhoods to an iterated local search.

This research is funded by Innovate UK under the Wind Farm Autonomous Ships Project (WASP), and we acknowledge the information about the application area provided by the project partners L3 ASV, Houlder Ltd, SeaPlanner Ltd, and the Offshore Renewable Energy Catapult.

■ TA-41

Tuesday, 8:30-10:00 - Q013

Integrated Public Transportation

Stream: Public Transportation I

Invited session

Chair: *Philine Schiewe*

1 - Aperiodic public transport timetabling with flexible line plans

Joao Fonseca, Evelien van der Hurk, Gabor Maroti, Roberto Roberti

Timetabling problems in public transport take as input line plans, stopping patterns and desired hourly frequencies. In the aperiodic timetabling problem with line planning elements (AT-LP) we allow changes in the line plans with the objective of maximizing passenger service, measured as a function of in-vehicle travel time, transfer time, transfer penalty, and waiting time. For a timetable to be feasible it must respect track section headways, station headways, station capacities. Furthermore we define lower and upper bounds on how much line plans may be changed. We present a heuristic approach to solve the AT-LP. Given a fixed Origin-Destination-Time matrix, we compute an initial feasible timetable. Modifications to the timetable in the form of shifting trips, adding and removing dwell time, skipping and adding stops, and increasing and decreasing frequency are then applied. Solutions that maximize passenger service respecting a budget on operational costs (measured as train.minutes cost) are accepted. Results for a case study using a train network in The Netherlands indicate that including line planning modifications allows obtaining timetables with increased passenger service when compared with using only timetable modifications. We use a lower bound on passenger service to compare the results obtained by our methodology.

2 - Solution Approaches to the Integrated Line Planning, Timetabling and Passenger Routing Problem

Philine Schiewe

Line planning and timetabling are two well researched problems in public transport planning. While in the line planning stage, fundamental connections in the infrastructure network are developed, times are fixed for all departure and arrival events of the lines in the timetabling stage. However, the quality of a line plan and a timetable can only be evaluated for a given passenger routing which determines the paths of the passengers and therefore the duration of their journeys. Instead of pursuing the classical approach where the stages line planning, timetabling and passenger routing are performed sequentially, we consider an integrated approach by building a line plan and a timetable simultaneously and routing the passengers during the optimization process. On the one hand, this integrated approach improves the solution quality while on the other hand it increases the computational challenge of finding an optimal solution. We therefore develop methods to reduce the problem size such that the integrated approach can be applied to medium sized instances. We present an exact preprocessing approach identifying unused arcs in the network as well as two heuristic approaches for reducing the number of routed passengers. We show the advantages of the integrated solution approach as well as the impact of the reduction methods experimentally on small and medium sized instances.

3 - Integrated timetabling and passenger route choice with stochastic disturbances.

Naut Bulten, Rommert Dekker, Shadi Sharif Azadeh

In our research we consider the train timetabling problem integrated with disturbances and passenger route choice. We assume the line planning to be given, and the goal is to determine the departure times of all vehicles on each of their stopping stations without imposing a repetitive structure like a basic hour pattern. The objective is to minimize the expected generalized travel times of all the passengers. The passengers are grouped into segments defined by their origin, destination, and desired time of arrival. To determine the expected generalized travel times, we apply sample average approximation using sets of disturbances. The solution consists of one planned timetable and numerous realized ones, different from the planned schedule through the disturbances. The passengers choose which train to take based on the planned timetable, but the evaluation is done based on the realized generalized travel times, which contain a penalty for delays. The difference between a disturbance and a delay is crucial here: a disturbance is an unexpected event which causes a train to require more than the minimum travel time between consecutive stations. A delay occurs when there is a difference between the planned timetable and the realized one. In our model the timetabler has the option to reduce delays by using supplements. We apply a column generation technique on several instances and discuss numerical results with a focus on the comparison between cyclic and acyclic timetables.

4 - Integrated approach for frequency setting problem and timetabling design for the synchronization of lines at common stops

Yadira Isabel SIlva Soto, Omar Ibarra

The design and planning process of transport systems involves solving the complex subproblems which are Transit Network Design, Frequency Setting, Timetabling Design, Vehicle Scheduling, and Driver Scheduling, in order to improve efficiency in user mobility by sequential methodologies. Is possible to obtain good-quality solutions using sequential approaches, but this does not guarantee an optimal solution to global planning. In response, the integration of subproblems arises as an efficient tool to obtain better solutions. In this study, we address a new integrated approach between frequency setting problem and timetabling design with synchronization of groups of lines in common stops in order to minimize the average waiting time, assuming feasible time windows and given functions for the travel time of transit lines. On the other hand, given a feasible set of frequencies for each line, a frequency must be chosen to define the number of trips per hour for each line. Then, our integral problem determines the frequency of each line and the departures times for all trips such that the weighted sum of average waiting time and operational cost is minimized. Preliminary results, using a commercial solver, show that we cannot find high-quality solutions in reasonable times even for instances of small size, we propose the implementation of a BRKGA, as well as the multi-objective variant of the problem and algorithm to explore the trade-offs between these two objectives.

■ TA-42

Tuesday, 8:30-10:00 - Q113

City logistics I

Stream: Transportation
Invited session
Chair: Fabien Lehuédé
Chair: Stefan Irnich

1 - Optimization of Last-Mile Delivery Fleet Considering Drone Deliveries and Demand Uncertainty
Mei-Ting Tsai

With the rise of e-commerce, demand for last-mile logistics increases significantly. In order to make deliveries more efficiently and economically, logistics providers keep looking for innovative solutions. Unmanned vehicle delivery service, such as delivering goods by drones, is one of the innovations. This study attempts to investigate the optimal fleet management incorporating with uses of drones and uncertainty of demand. It is not only considering whether the drone should completely replace the traditional trucks, but also the most suitable portfolio depending on the nature of the service provider's order characteristics. Specifically, this study solve the problem using stochastic optimization to find the optimal portfolio of trucks and drones corresponding to uncertain order quantity, order size, delivery distance, and density of distribution, while minimizing the total operating costs. A numerical example is conducted based on a service provider's delivery data, and is solved by using linear programming in Matlab. As a result, this study identifies the conditions that drone deliveries are most valuable, and develops a decision support model that provides the best combination of delivery tools, as long as substituting the relevant data into the model.

2 - Maximizing the Number of Available Delivery Slots in Attended Home Delivery Systems
Christian Truden, Philipp Hungerländer

Attended Home Delivery (AHD) systems are used whenever a supplying company offers online shopping services that require that customers must be present when their deliveries arrive. Therefore, the supplying company and the customer must both agree on a time window during which delivery is guaranteed. Typically, a capacitated Vehicle Routing Problem with Time Windows forms the underlying optimization problem of the AHD system. When placing a new order, the customer receives a selection of available time slots that depends on his address and the current schedule. The customer chooses his preferred time slot, and his order is scheduled. The larger the selection, the more likely the customer finds a suitable time slot, leading to higher customer satisfaction and a higher overall number of placed orders. We denote the problem of determining the maximal number of feasible time slots for a new order as the Slot Optimization Problem. We propose a solution approach that allows to determine which delivery time windows can be offered to potential customers. We propose several heuristics for both determining feasible and infeasible slots. Our approaches combine local search techniques with strategies to overcome local minimas as well as integer linear programs for selected sub-problems. In an experimental evaluation, we demonstrate the efficiency of our approaches on a variety of benchmark sets and for different time restrictions that are motivated by varying customer request rates.

3 - Integrating lockers and multiple delivery options in a city logistics distribution system
Fabien Lehuédé, Dorian Dumez, Olivier Péton

The growth of e-commerce is stressing last-mile delivery services. Some solutions are being developed to avoid delivery failures. Classically, parcels are delivered into mailboxes. They can also be delivered in shared locations such as shops or lockers boxes. During worktime, packages can also be delivered at work in some companies. We define the Vehicle Routing Problem with Delivery Options, which generalizes the VRP with time windows, integrating several delivery locations per request. Each location can be associated with a time window and a priority level, and called a delivery option. We consider several types of delivery locations, including lockers which may introduce some synchronization between routes due to their limited capacities. An overall service level is defined based on prorities. Consequently, the set of routes must serve all clients through exactly one option, respect the time windows and the synchronized resources constraints.

To solve this problem, we design a LNS coupled with a set partitionning formulation. It integrates specific operators as well as operators adapted from the VRPTW. The method is evaluated on randomly generated instances and on the VRPTW benchmarks.

4 - Routing of Vans and Embedded Drones for Parcel Delivery
Olivier Gallay

Directly inspired by an industrial application currently under development at a large European mobility provider, we evaluate in this contribution how vans and autonomous drones can be combined in the context of parcel delivery. We consider the situation of a mixed-fleet of vehicles where drones are embedded into the delivery vans, and where the drones can leave the vans along their route with parcels to be delivered at customer locations, and then come back to be refilled and recharged. On the one hand, drones are cost efficient and more agile, but suffer from low range and reduced room space for parcel storage. On the other hand, vans are more expensive to operate and induce a larger ecological footprint, but offer larger autonomy and increased capacity. In a static day-ahead context, we propose a dedicated adaptative large neghborhood search (ALNS) to generate routing solutions that take advantage of the specific characterisitics of each of these two transport modes. While autonomy and capacity issues prevent from implementing a delivery fleet consisting of drones only, we show that synchronizing them efficiently with vans yields substantial cost savings in comparison to a classical fleet including vans only.

■ TA-43

Tuesday, 8:30-10:00 - Q114

Facility location in transportation networks

Stream: Location Analysis and Optimization
Invited session
Chair: Lotte Verdonck

1 - Optimal Facility Location Model for Freight Vehicles to Exploit Buffer Times Efficiently
Yohei Kakimoto, Hiroyuki Goto, Panote Prommas, Yoichi Shimakawa

A facility location model for transportation planning, to increase operational efficiency of a road network, is proposed. There are many potential factors that may decrease operational efficiency, one of which is waiting times by freight vehicles on streets. In transportation planning contexts associated with freight vehicles, buffer time is key to reduce the risk of delay. Extra vehicles as well as hubs are prepared. However, excess resource assignment would force freight vehicles to wait on a street to observe the scheduled times. This would impact the efficiency of operation. Consumption of buffer times would be at facilities located for a particular purpose to wait. If vehicles can share facilities in an efficient manner to reduce waiting times, then the operation of the road network is efficient. The flow-capturing location-allocation model (FCLM) is a traditional location model for facilities capturing traffic flows. However, it solely focuses on maximizing the covered traffic flows. In location planning contexts for facilities aiming to consume buffer time, the following two factors needs to be considered as well, (1) temporal relationship to reduce buffer time, and (2) capacities of facilities. The former (1) is attained by adjusting the total buffer time of all freight vehicles to zero. The latter (2) is achieved by considering an upper traffic flow that a facility is capable of serving. The proposed model extends the conventional FCLM to account for these elements.

2 - The Impact of Depot Location on Rolling Stock Scheduling with Maintenance Requirements
Richard Lusby, Qingwei Zhong, Jesper Larsen

Rolling stock scheduling with maintenance requirements is a topic that has received increased attention in the literature. Rolling stock scheduling involves assigning compositions to a set of timetabled trips in such away that the provided capacity matches the forecast passenger demand and any unnecessary (de)couplings and or dead-heading movements are avoided. The inclusion of unit-specific maintenance restrictions further complicates this problem. Typically, the location of the depots, or places in the network where composition changes and maintenance occurs, are assumed known. The locations where maintenance can be performed naturally influence the maintenance possibilities and ultimately the quality of any resulting rolling stock schedules. Motivated by network expansion at the Chinese High Speed Railway, in this talk we consider the problem of selecting new depot locations. We extend a two stage Mixed Integer Programming approach for Rolling Stock Scheduling with Maintenance requirements to account for depot selection, and test the proposed methodology on real-life instances from the Chinese High Speed Railway.

3 - Transfer station allocations in urban solid waste transportation system
Pradeep Rathore, Sarada Prasad Sarmah

Transportation system of solid waste constitutes around 80% of the total fund allotted to municipal solid waste management. It consists of many facilities such as collection bins, transfer stations, processing plants, and landfills. Presently, municipalities of many cities in developing countries are facing the problem of insufficient facilities. This is increasing the cost of transportation of municipal solid waste. Therefore, this study proposes an approach to the determination and site selection of transfer stations. Transfer stations are intermediate facilities between solid waste generation sources and disposal facilities. They are used to transfer the waste from lightweight carrying vehicles to heavyweight carrying vehicles in order to decrease the transportation cost. This study proposes a mathematical optimization model for determining the transfer stations. The novelty in the developed model is the strategic allocation of transfer stations while considering the source separation of MSW. The optimization model is written and solved in linear programming solver CPLEX 12.2. The proposed approach has been verified by applying to an Indian city. Optimization model selects six best locations for allocation of the transfer station at an overall cost of INR179,739 (USD 2696) per day for Scenario (I). While in Scenario (II) it is providing six best locations for allocation of the transfer station at an overall cost of - Rs. 78036 (-USD 1170) per day.

4 - Optimising the cooperative carrier facility location problem under demand uncertainty
Lotte Verdonck, Patrick Beullens

Due to its practical importance, collaborative logistics has developed into an active and growing research domain. Existing studies mainly focus on collaborative transport in order to increase the efficiency of vehicle fleet operations. Instead of optimising joint transport operations, carriers may also cooperate by sharing warehouses or distribution centres (DCs). By jointly deciding on two types of decisions, namely, first which DCs to open, and, second how to allocate the quantity of product flows in the distribution network, partnering companies aim to minimise their total logistics cost. In addition, the carriers have to decide on a suitable distribution of the collaborative benefits while ensuring stability of the coalition. The majority of studies on collaborative logistics assume deterministic problem settings. Very few studies address how horizontal collaboration between carriers can work in a stochastic environment. As such, our research work investigates approaches to the optimisation of the cooperative carrier facility location problem in a market environment characterised by demand uncertainty. We can draw on past research on the facility location problem under uncertainty, but the context of horizontal carrier collaboration introduces additional challenges with respect to the assessment and sharing of risks and the robustness of coalition stability.

■ TA-46
Tuesday, 8:30-10:00 - L243

Engineering Optimization

Stream: Engineering Optimization
Invited session
Chair: *Wolfgang Achtziger*

1 - The development of optimization scheme for searching optimal design variables to satisfy target mechanical properties in steel product
Jung Hyeung Lee

In recent years, the major steel companies all over the world have faced intense competitions against each other because of an oversupply of steel products, especially in East Asia. To increase market share, it has been an important issue to reduce production cost without quality degradation. To handle this issue, this research is focused on developing optimization scheme to determine optimal process and alloy conditions in steel product, which is automatic simulations based on heuristics, that is, multiple objective particle swarm optimization (MOPSO) using the concept of Pareto optimality , replacing experiments by human to reduce trial and error in applying real industry field. The Pareto solutions give us the optimal trade-off solution among competing objective functions. In industry, although the Pareto solutions are optimal candidates, they commonly have extreme process conditions, that is, they are dangerous or challenging to implement. So, allowing for the degradation more than one objective function, the many more solutions in the vicinity of the original optimal solution can be considered as second optimal candidates for application, which surely gives the decision maker more opportunities for determining more safe and applicable solutions. To do this, the concept of a Meta Pareto front was suggested in this research.

2 - A new hybrid model for iron ore blending problems using Particle Swarm Optimization and Linear Programming
Akira Kumano

In this paper, we propose an original optimization algorithm for an iron ore blending problem in steel industry. In a raw material operation, huge amount of iron ore are blended for producing high quality sintered ore every day, and there is much possibility of cost saving. The primary purpose of the blending problem is to obtain the minimum cost blending plan which satisfies several constraints such as the stock in yards, ingredients of sintered ore. However, nonlinearity appearing in some constraints makes this optimization problem difficult to solve numerically in a short time. In the actual operating, human operators fixed these nonlinear variables and solved manually. In order to treat nonlinear constraints and shorten the calculation time, we decompose the original problem into two stages. In the first stage, we assign numeric values to nonlinear variables to obtain the linearized optimization problem and Particle Swarm Optimization is introduced to search the optimal numeric values effectively. In the second stage, Linear Programming contributes to a quick calculation for each linearized problem. Iterations of these two stages realize a quick convergence to the optimal solution. Numerical simulation using a practical data showed the effectiveness of our method not only in the cost reduction of the obtained solution but also the quickness of the calculation.

3 - Dual Response Surface Optimization Of One Side Single Quality Characteristic Using The Cpk Process Indicator Index
Michael Bendersky, Yisrael Parmet

Dual Response Surface Methodology (DRSM) is a powerful tool for simultaneously optimizing the mean and the variance of a quality characteristic in the field of quality engineering. The optimization of dual response systems to achieve better quality has played a major role in the design of industrial products and processes. Known methods for DRSM focus on minimizing or maximizing the mean, variance or a combination of the two (set according to the production process) without taking into account the specification levels (usually set by the consumer). In this paper, we suggest using the CPK - a process capability index - as the objective function. The CPK incorporates the mean, variance and the specification levels of the process. We show by ways of multiple examples that this method improves the obtained yield of a process for different response variable types.

4 - On First Order Necessary Optimality Conditions in Structural Topology Optimization
Wolfgang Achtziger

We consider classical formulations of topology optimization problems for discrete/discretized engineering structures in a rigorous setting, i.e., we allow zero design variables in a mathematical simultaneous analysis and design ("SAND") problem formulation. Standard numerical solution procedures typically fail to calculate correct local minimizers of such problems. The background lies in the fact that these solvers are based on the standard first order optimality conditions and on certain regularity assumptions. Meanwhile it is well understood that these regularity conditions usually are violated. Even worse, it is unclear whether at local minimizers the standard first order optimality conditions are satisfied at all. The talk presents some insight into this topic and presents some proof sketches and new results on problem formulations for which the first order optimality conditions are satisfied. A key in these investigations are, e.g., certain properties of the stiffness matrix, of compliance and of weight. These results are useful for the development of appropriate perturbation approaches enabling standard numerical solvers to calculate correct minimizers. A part of the talk presents joint results with Ch. Schürhoff.

■ TA-47

Tuesday, 8:30-10:00 - L247

Behavioural marketing and forecasting

Stream: Behavioural OR
Invited session
Chair: Christopher Holland

1 - The effectiveness of digital advertising
Gil Greenstein

Firms use the internet to promote their products and services since it has gained enormous importance as an advertising medium. Therefore, the study of marketing accountability has become a major issue for researchers and practitioners. In addition, using search engines has become an integral part of the way the firms advertise online. The purpose of this study is to evaluate the effectiveness of digital (internet) advertising, using a search advertising platform (Google AdWords). On this platform, there are various parameters that affect the results of the campaigns, some of them controlled by the advertiser, and some are controlled by the search advertising platform administrators. The study examines these factors in order to better understand their impact on the success of the campaigns. The study uses the data of four campaigns that were lasted for three months each, and tries to measure their success. The real data set contains the details of 57,720 search results: keywords that were relevant for the firms which participated in the campaigns, date, number of clicks and so on. It includes all cases when the advertisement was exposed, regardless of whether there was a click or not. The data set is used to analyze the relationship between the outcomes of the internet advertising campaign and its cost and timing. The results of the study may be useful in decision processes on an advertising campaign.

2 - Collaborative forecasting behavior of humans and machines incorporating the concept of eXplainable AI
Tim Lauer

Both machines and humans have distinctive advantages when it comes to forecasting tasks, meaning that a collaborative approach is necessary to utilize the strengths of both actors, for creating synergies. The phenomenon of algorithm aversion obstructs collaboration. This thesis takes on a novel angle to overcome algorithm aversion and foster collaboration, by addressing the lack of explainability in algorithms through the concept of eXplainable Artificial Intelligence. The aim is to test whether more explainability in algorithms leads to a higher degree of collaboration and whether such enhanced collaboration leads to performance improvement. The created framework allows for conducting behavioral experiments of forecasting scenarios to answer the above. Initial significant results are obtained regarding the effect of explainability on algorithm aversion. Participants receiving more explainability on the algorithm followed the algorithm's advice more under non-explicit feedback conditions. A tendency of improved performance was discovered for a higher degree of collaboration.

3 - The online customer journey: Markov chain analysis of clickstream data
Christopher Holland

A challenge at the interface of behavioral OR and digital marketing is to understand how customers search for products; this process can be modeled as a series of discrete decision choices. Whilst discrete modeling using Markov chain theory is theoretically attractive it is very difficult to implement because of the significant data requirements. The most direct way of addressing this problem is to use clickstream data, which accurately measures customer behavior at scale. There are two types of clickstream data: (1) web server data from an individual company; (2) online panel data that tracks behavior across multiple websites. Panel data provides information about the broad search pattern including journey length, consideration set and time allocation. Web server data provides detailed insights into the search, buying and e-service patterns on an individual website, i.e. for an individual brand. A synthesis of the two data sources is evaluated using Markov Chain analysis. This approach encompasses the evaluation of competing brands and use of search intermediaries through to the detailed configuration of an individual purchase. The ideas are applied to the airline market with a data set composed of web server data from a European airline combined with commercial panel data. The managerial implications of the model and results are discussed and future search opportunities outlined.

■ TA-48

Tuesday, 8:30-10:00 - L248

Energy and Heating Models

Stream: Applications of Dynamical Models
Invited session
Chair: David Raz

1 - Techno-economic evaluation of combined micro power and heat generation assets: Implications for the multitenant building market in Germany
Reinhard Madlener, Gedeon Zimmermann

We propose a deterministic techno-economic model that defines optimal local power and heat generation setups for multi-tenant buildings in Germany. We consider sets of micro-generation technologies, such as solar photovoltaics (PV), combined heat and power, heat pumps, and storage systems for thermal energy. Technical and economic data for devices, prices and remunerations for electricity and thermal energy, local demand profiles and specifications for houses, as well as PV production profiles are the input data for this "big data" model. The goal is to investigate whether the investment in new power plants is worthwhile for the multi-tenant energy service provider who fulfills the role of negotiating between owners and tenants, thus creating a win-win situation for the participants in this business model. We find that for small tenements, PV-only is the best option. For larger tenements, scale effects occur and a deep retrofit is economical.

2 - A brazilian long-term oil refining analysis within the energy transition
Frederic Lantz, Fernanda Guedes

The oil consumption should represent a reduced share of the energy consumption during the next decades to limit the Green House Gas Emissions. Nevertheless, the crude oil consumption will likely remains important. The world oil market is passing by a transition phase, which is spurred by several factors, such as the transformation in the transportation sector (with less oil products). In this context, Brazil is in a situation with both an important crude oil availability and an ambitious environmental policy with a significant biofuel supply. Thus, an optimal pattern between should be defined considering the energy needs, the environmental targets and the economic factors. Consequently, the objective of this study is to analyze, through the development of a linear programming optimization model, the evolution of the Brazilian oil refining industry and the carbon emissions at the level country athwart oil products demand scenarios and environmental policies. Because, this refining activity as well as the biofuel supply couldn't be only considered at a level country, we use a nested approach. We run a Worldwide aggregated LP dynamic model of the refining industry considering several main areas among which Brazil is identified. Then, using the global results, we run a LP model for the Brazilian refining industry and biofuel supply. We pay a particular attention to the robustness of the results due to the relationship between the Worldwide and the domestic models.

3 - A multi-objective online optimisation tool for smart home heating solutions
Caroline Schäfer, Alexander Baumeister

Smart home heating solutions - a combination of IoT and traditional heating devices that allows optimising heating plans based on advanced control methods including contextual information - should increase users' comfort and save heating energy compared to manual control. Nevertheless, its use is not yet widespread. Incorporating intelligent supervisory control for heating systems into the residential sector requires flexible handling of different user preferences, widely self-explaining ease of use in the setup and minimising user intervention, but at the same time high reliability of the initial parameter settings and mainly self-adaptation to changing conditions. Our presented solution aims at resolving the dilemma between restricted users' comfort during a training phase using autonomous learning for heating supervisory control and the challenge of knowledge-extensive, accurate parametrisation of model predictive control for non-expert users. The developed prototype of an online optimisation tool for smart home heating solutions incorporates a user-preference-driven multi objective (e.g. minimising lifecycle energy (cost) or carbon emissions) model predictive control problem under constraints such as thermal comfort. While the online optimisation tool is based on a discrete dynamic model, its self-adaptation is accelerated by a database of physically simulated characteristic buildings, which allows parameter setting at the beginning by a similarity measurement.

4 - A Multi-objective Approach for Volt-VAr-Control through Integration of Grid Edge Devices with Traditional Methods
David Raz, Ariel Daliot, Yuval Beck

Traditionally, distribution systems include Volt-VAr-Control (VVC) devices, such as capacitors banks and transformer tap changers, that target to maintain the voltage within allowable limits. The revolution of smart grid introduced smart equipment and edge technologies up to the distribution transformer and even inside the facilities and customer premises. We present a generalized holistic approach for integrating VVC resources with Distributed Energy Resources (DERs), such as photovoltaic farms and customer premises batteries, as well as other edge devices, in order to achieve various VVC target functions such as Conservation voltage reduction (CVR), zero VAr flow at the transformer or minimal grid losses. The approach enables the operator to set multiple objectives and takes into consideration the constraints of the system such as keeping the voltage within allowable limits. We introduce a method for reduction of complex distributions system into a simplified form, which enables the fast execution of the power flow calculations. We analyze various multi-objective approaches and show how these methods can be used or assessing the trade-off between the different objectives. Examples supporting this holistic approach are shown, demonstrating the capabilities of the method.

■ TA-49

Tuesday, 8:30-10:00 - L249

Software for optimization model deployment

Stream: Software for Optimization
Invited session
Chair: Jens Schulz

1 - New Python Integration Features of the AMPL Modeling Language
Robert Fourer, FIlipe Brandão

Optimization modeling languages are fundamentally declarative in design, but are frequently put to use within broader contexts that require a variety of programming options. Thus while programming is not employed to describe models, it facilitates the integration of models into broader algorithmic schemes and business applications. This presentation focuses on integration of the widely used AMPL modeling language with Python and Jupyter, the most popular environment for programming in data science. A single running example illustrates multiple topics, which include integrating model-based optimization into applications using AMPL's Python API, embedding Python in AMPL models and scripts, implementing complex AMPL constraint generators in Python, and setting up solver callbacks using Python programs.

2 - Model deployment in GAMS
Frederik Proske, Robin Schuchmann

In most cases, using GAMS in the typical fashion - i.e. defining and solving models and evaluating the results within the given interfaces is a sufficient way to deploy optimization models. The underlying field of mathematical optimization, in which the focus is not so much on visualization as on the problem structure itself, has remained a kind of niche market to this day. In the large and very extensive segment of business analytics, however, intuitive deployment and visualization is indispensable. Since these two areas increasingly overlap, interest in alternative deployment methods is also growing in the field of mathematical optimization. In this talk we present a new interface to deploy GAMS models. We show how to turn a model into an interactive web application in just a few steps. In addition, the generation, organization, and sensitivity analysis of multiple scenarios of an optimization model is addressed. We demonstrate how a model written in GAMS can be deployed with this application on either a local machine or a remote server. While data manipulation and visualization as well as scenario management can be done via the web interface, the model itself is not changed. Therefore, the Operations Research analyst can keep focusing on the optimization problem while end users have a powerful tool to work with the data in a structured way and interactively explore the results.

3 - Optimizing in the Cloud - Deploying Optimization Models on the Cloud with REST API Server and JSON
Bjarni Kristjansson

Over the past decade the IT has been moving steadfastly towards utilizing software on clouds using Web Services REST API's. The old traditional way of deploying software on standalone computers is slowly but surely going away. In this presentation we will demonstrate the MPL REST Server written in Python Flask, which allows optimization models to be easily deployed on the cloud.

By delivering optimization through a standard REST API, which accepts data in JSON and NoSQL formats, the optimization becomes purely data-driven. We will demonstrate examples on how using the JSON data format can be particularly well suited for managing and delivering data to optimization solvers.

Client applications can now be implemented relatively easily on different client platforms such as mobile/tablets or web sites, using just standard HTML/CSS with JavaScript, or any other preferred programming language.

4 - From an experimental model to a successful operational deployment
Jens Schulz

Digitization, AI, Machine Learning, and Optimization are the latest buzzwords in technology. Yet, how much value are they really delivering to the enterprise? Success stories from some of the world's biggest brands highlight their potential: data transparency, insights on processes and interrelation, a single point of truth for decision making, cost reduction, increasing customer service, etc. However, per Gartner, over half of these projects are never fully deployed. Instead of being operationalized in the business, they remain as science projects in the lab. Why? They fail to be executed the last mile - getting their work in the hands of business users. Business users are the ones making day-to-day decisions for the enterprise!

In this session, we will show you how to successfully deploy analytic and optimization models with FICO Xpress and, in particular, FICO Xpress Insight. Xpress Insight, a web deployment platform, enables solution developers, data scientists, and OR experts to rapidly develop and deploy applications. Moreover, it enables them to collaborate with the business experts in every stage of the development process from model creation to model deployment. To unleash the real power of optimization, it needs to move out of the lab and into the operations of the business. We will highlight best-practices and showcase how our tools can be used throughout the project to generate trust and inspiration for both technical and business experts.

■ TA-50

Tuesday, 8:30-10:00 - Mason Hayes & Curran

Theoretical developments in Problem Structuring Methods

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: Leroy White

1 - The Mangle IN Practice: A potential new methodology for OR?
Christina Phillips

We take a look at the Mangle of Practice as developed by Andrew Pickering and extended for use in BOR by Richard Ormerod. Having used the mangle as a theoretical lens in multiple interventions in practice we develop a view on why it works to view socio material systems and its potential to define a new methodological approach. The mangle is unique in taking a performative view of scientific development which views not just humans as actors but all other aspects of a system as well, to create a 'decentred dance of agency' as Pickering (1995) romantically refers to it. Computers, algorithms, processes, systems and tools all have agency as each can be mutated and transformed as new systems evolve during OR interventions. This view has the power to enable new theoretical development but it also has a deeper view of the performance of OR and in this respect provides a framework which could enhance OR interventions in practice, particularly those which involve bringing together social and technical systems. The mangle's constitutive parts provide a way to view change as it occurs in practice during an OR intervention. If taken a step further could this actually be a way to approach interventions that provides a change management process that can be used alongside other OR techniques?

2 - Everyday Problem Structuring Practice
Eleanor Reynolds

What happens when OR practitioners are not there? Asking how people engage in everyday problem structuring, this research identifies and theorises naturally occurring episodes of problem structuring within an everyday organisational context. Conceptualising everyday problem structuring as a practice this ethnographic study initially identified the significance of both inward and outward connecting objects within episodes of problem structuring. The fieldwork developed, following links between people and projects across the organisation via these connecting objects. Purposeful agents were observed bringing company objects into problem structuring episodes (inward connections) and taking objects created by a particular group elsewhere within the organisation (outward connections). Within and between groups, acts of alignment, misalignment and non-alignment were seen to impact the use and interpretation of connecting objects, in turn affecting problem situation perspectives and acceptance of problem frames.

3 - Developing a generic Problem Structuring Method: The philosophical, theoretical and methodological development of WASAN from the specific, to the generic.
Chris Smith

This paper considers the philosophical, theoretical and methodical development of the context specific approach WASAN into an approach that could be considered a generic problem structuring method. The Nuclear Installations Inspectorate commissioned the development of WASAN to analyse the reduction of avoidable radioactive waste. Such, it was developed with a very specific context in mind, adhering to specific regulations and using a particular jargon. The concept of waste reduction is useful for a wider set of clients, such this paper looks at how WASAN was developed to be used in a UK Police Force contact centre. WASAN was developed through an action research programme through 10 learning loops, providing learning about the area of concern, the methodology WASAN and the framework of ideas underpinning this. The focus of this paper is the learning related to the developing WASAN generically. This focusses on two important issues, first does WASAN exhibit the properties of other PSMs, shown through the 4 pillar framework. Second, focusses on the different classes of elements within the WASAN methodology that are required for it to be generically applicable. That is it can be applied to a variety of problem contexts without need for further methodological development.

4 - The strategic choice approach as temporal work
Leroy White

It is often said that the strategic choice approach (SCA), as an example of a problem structuring method, lacks a theoretical basis, leading to concerns about its efficacy. In this presentation I would like to revisit this supposition to argue the contrary. From it onset and through its action research pedigree, SCA has raised a number of interesting questions. For scholars of soft OR, they are around process; and for planners response to the questions has led to invaluable tips for practice. For the pioneers of the approach, the concern has always been for handling uncertainty. At the heart of this concern is temporal work (see Kaplan & Orlikowski, 2013). This could be defined as negotiating and resolving tensions among stakeholders for a better understanding of actions in the past, what is needed in the present, and what might emerge in the future. This presentation focuses on how with SCA temporal tensions are negotiated and resolved.

■ TA-51

Tuesday, 8:30-10:00 - William Fry

Optimal Control Applications 1

Stream: Optimal Control Theory and Applications
Invited session
Chair: Guiomar Martin-Herran

1 - When Does Eco-Efficiency Rebound or Backfire? An Analytical Model
Régis Chenavaz, Stan Dimitrov, Frank Figge

It is known that an eco-efficiency strategy, which save ressources in the production process, may be offset by a rebound effect; it may even backfire. Less known are the exact conditions under which eco-efficiency rebounds or backfires. This article fills the gap by providing an analytical model of the rebound and backfire effects. We propose an optimal control framework of dynamic pricing and eco-efficiency investment, for which eco-efficiency reduces the unit production cost and boosts the demand of green consumers. Results, which hold with general demand formulations, examine the analytic conditions for the rebound and backfire effects. They also highlight the possibility of a reverse rebound effect. Such results pave the way to sounder green economic strategies.

2 - Resource Scarcity and the Inert Buildup of Backstop Technologies Characterized by Learning and System Costs
Gernot Tragler, Magda Mirescu

Climate change is one of the most urgent challenges of the current century. One contribution to prevent it from happening is by shifting from pollution-intensive to climate-friendly or so-called backstop technologies. This paper investigates the optimal expansion of backstop technologies in the realistic setting of scarcity of non-renewable or fossil resources.

Fossil-fuelled technologies are assumed to be already available and to require exhaustible resources, which are characterized by extraction costs but also by damage done to the environment. Backstop technologies, on the other hand, require high investment costs to be built, which in turn imply a lethargic increase in their installed capacity. Additionally, two counteracting effects are assumed for backstop technologies: the well established effect of learning-by-doing (which diminishes the very high investment costs) and the knock-in effect of system costs (which prevents the integration of too high a share of backstop technologies as this could become very expensive to the overall system due to their variability and undispatchability).

From a modelling perspective, this paper contains a deterministic, non-linear optimal control model with two states and two controls. The main result is that the learning effect facilitates the integration of more backstop technologies thus preserving the exhaustible resource, while the knock-in effect punishes backstop and increases the dependence on the fossil resource.

3 - A Dynamic Private Property Resource Game with Asymmetric Firms
Luca Grilli, Michele Bisceglia

In this paper, we consider a non-cooperative differential game in which two competing firms privately hold the same resource in order to produce a common good. We suppose that each firm can determine a different growth rate for the resource according to private technology owned by each firm. In particular, we assume that there is one x - efficient firm, which is able to breed the resource stock to the maximum allowed rate given the "environmental conditions", and the other firm accusing a certain efficiency gap caused by a technology that does not allow it to take full advantage of the resource growth potential. We find an asymmetric linear Feedback Nash Equilibrium (FNE) in which the player's strategy only depends on his own resource stock (regardless of the resource assigned to the other player). We show the optimal path obtained by the FNE both for the asset stock and for the firms' output levels and we carry on short-run and steady-state analyzes, also from a social welfare point of view.

4 - Present bias and the inefficiency of the centralized economy. The role of the elasticity of intertemporal substitution
Guiomar Martin-Herran, Francisco Cabo, Maria Pilar Martinez-Garcia

We analyze an endogenous growth model with non-constant discounting and a pollution externality affecting utility. With a decreasing rate of impatience time-consistent agents anticipate the behavior of their future selves and play a game against them. The strategic interaction between subsequent central planners implies slower growth than the market solution, where the pollution externality is not internalized. Indeed it can be too slow from a social welfare standpoint. Contrary to exponential discounting, for any non-constant discount function we prove that the market equilibrium is Pareto-improving provided that the pollution externality is sufficiently small. For a specific family of non-constant discount functions we observe that the range of values for the environmental externality compatible with a Pareto-improving market solution widens with the elasticity of intertemporal substitution in consumption. Similarly, this range also widens the more different from constant discounting time preferences are: either due to a wider range of variation of the instantaneous discount rates, or because they decay more slowly.

Tuesday, 10:30-12:00

■ TB-01

Tuesday, 10:30-12:00 - O'Reilly Hall

Holger Hoos

Stream: Tutorials
Tutorial session
Chair: *Christina Büsing*

1 - Programming by Optimisation: Automated algorithm configuration, selection and beyond
Holger Hoos

In recent years, there has been a significant increase in the use of automated algorithm design methods, such as automated algorithm configuration and portfolio-based algorithm selection, across many areas within operations research, artificial intelligence and beyond. These methods are based on cutting-edge machine learning and optimisation techniques; they have also led to substantial advances in those areas.

In this tutorial, I will give an overview of these automated algorithm design methods and introduce Programming by Optimisation (PbO), a principled approach for developing high-performance software based on them. I will explain how PbO can fundamentally change the nature of developing solvers for challenging computational problems and give examples for its successful application to a range of prominent problems from OR and AI - notably, mixed integer programming, the travelling salesman problem, AI planning, automated reasoning and machine learning.

■ TB-02

Tuesday, 10:30-12:00 - Moore Auditorium

EEPA 2

Stream: EURO Excellence in Practice Award
Award Competition session
Chair: *Erik Demeulemeester*

1 - The Volkswagen Pre-Production Center Applies OR to Optimize Capacity Scheduling
Christian Weckenborg, Karsten Kieckhäfer, Thomas Spengler, Patricia Bernstein

Maximizing the utilization of resources is a frequently pursued optimization measure in industrial manufacturing. The planning task of capacity scheduling contributes to this objective by deciding on resource allocation and scheduling of orders. Since the Volkswagen Pre-Production Center (VPC), responsible for the entire prototype assembly of the Volkswagen brand, had been suffering from fluctuations of manufacturing personnel utilization at generally lower utilization levels we were asked to evaluate possible OR/MS solutions for their capacity scheduling problem. To this end, we developed a prototype for capacity scheduling based on binary integer programming. After the prototype had revealed high optimization potential, we developed a fully-fledged decision support system (DSS) for daily operation of capacity scheduling. It turned out that the schedules generated by the DSS were substantially better than the solutions generated by the current manual procedure, both in terms of resource utilization and planning effort. After successful test implementation and roll-out, the VPC estimates the annual cost savings to lie in the six-digit euro range. Meanwhile, we continue spreading OR/MS methods in neighboring departments of the VPC.

2 - An Efficient Hybrid Column Generation Approach for Practical Railway Crew Scheduling with Attendance Rates
Janis Sebastian Neufeld, Kirsten Hoffmann, Martin Scheffler, Felix Tamke, Udo Buscher

The crew scheduling problem with attendance rates is a highly relevant problem for regional passenger rail transport in Germany. Its major characteristic is that only a certain percentage of trains have to be covered by crew members or conductors, which increases complexity significantly. Even though this problem is commonly found in regional transport networks, still it has been discussed rarely in literature and no automated planning support exists in practice. We propose a novel hybrid column generation approach for a real-world problem in railway passenger transport. To the best of our knowledge for the first time several realistic requirements are integrated that are necessary for a successful application of generated schedules in practice. While an extended mixed integer programming model is used to solve the master problem, a genetic algorithm is applied for the pricing problem. Several improvement strategies are applied to speed up the solution process. These are analyzed in detail and exemplified. The effectiveness of the proposed improved algorithm is proven by a comprehensive computational study using real-world instances. The developed approach is successfully used in practice at a large German railway company since 2017.

3 - Towards optimal alignment design for road construction - Using Optimization to Design Safe Roads at Minimal Cost
Yves Lucet, Warren Hare

Efficient transportation networks are critical to any economy. Optimizing a road design is a prime application for operational research since saving a few percent may add up to millions even on a single road.

Optimization of road design splits the problem into several nested stages. First, promising corridors are selected before a satellite view of the road is traced in each corridor (horizontal alignment problem). Next, cusp and crest are altered to obtain a road design that is safe to drive (vertical alignment problem), and finally materials are optimally moved to their best location (earthwork problem). In this talk, we overview modern techniques and recent advancements in optimization for road design.

In particular, we present an integrated model that captures both the vertical alignment and earthwork problem, and computes a globally optimal solution. The cost savings are validated on a representative set of 40-60 roads, with average improvements of 20-30%. The model achieves the required precision by considering side-slopes, multiple materials and various equipment, while keeping the computation time in an acceptable range. The result saves civil engineers significant design times and produce a solution that no human expertise can surpass.

■ TB-03

Tuesday, 10:30-12:00 - Q106

OR impact on societal problems

Stream: Practice of OR (Making an Impact)
Award Competition session
Chair: *Michele Quattrone*
Chair: *Dan Bumblauskas*

1 - Extending Capture-Recapture to Estimate Border Security
Paul Kantor, Vladimir Menkov, Dennis Egan

To maintain secure borders it is vital to measure the effectiveness of border security measures. Capture-recapture techniques have been proposed, augmented by biometric identification to play the role of "tagging." These models cannot deal with the confounding between deterrence and detection. We introduce a "two fluid model" which binarizes the effect of having been caught once. This permits estimation of the effectiveness of border security, by focusing on those identified persons who persist in border crossing, as probes of effectiveness. We explore the problems of (1) resolving the deterrence-detection confounding using non-linear optimization and (2) incorporating pseudo-Darwinian models, in which those persons who are repeatedly captured are modeled as belonging to the "low end" of a spectrum of "ability to avoid capture." We assess the theoretical analysis using simulation methods, and explore the path to application in realistic situations, where there are multiple paths by which to cross one or more borders. Research supported in part by the U.S. Department of Homeland Security Center of Excellence for Borders, Trade and Immigration.

2 - Justice in Time: Applying Operations Theory to Court Systems - The Case of the Jerusalem District Court
Shany Azaria, Boaz Ronen, Noam Shamir

If there is some truth to the old principle that justice must not only be done, but must be seen to be done, then surely it must be seen to be done in a timely manner. Nevertheless, court congestion and delays—which threaten to undermine the justice system—became a global phenomenon with significant adverse implications on social welfare, economic development and civil rights. In this research, we report on the application of several operations management tools to tackle this problem and help reduce congestion in courts. In cooperation with the Jerusalem District Court in Israel, we have implemented the following changes in the judicial process: (1) Introduction of a new planning and scheduling phase; (2) Modification of the hearing scheduling policy from hearing-based FIFO policy to case-based FIFO policy; (3) Shortening the summations stage by encouraging oral summations. We evaluate the effect of these operational changes by performing a before-after econometric analysis. Our results demonstrate a 40% reduction in trial time (the treated part of the process), which translates into 18.87% reduction in the total life cycle of a case.

3 - Letting a hundred data scientists bloom: harnessing the power of cutting-edge data science to improve the outcomes of critically ill children
Christina Pagel, Mark Peters, Padmanabhan Ramnarayan, Samiran Ray

BACKGROUND Advanced data science has been hailed as a game changer in delivering better health care. The UK NHS has many large datasets but these are messy, hard to interpret and the use of advanced data science techniques is still in its infancy. Operational Researchers could be key in meeting the challenge of how to mesh the highly technical world of data science with the realities of front-line clinical decision making.

The UK Turing Institute for data science runs regular Data Study Groups (DSGs) where a hundred top data scientists from all fields gather for a week of intense work on real-world problems.

Great Ormond Street Hospital (GOSH) has a unique high resolution vital sign dataset of 5500 children in intensive care and contributed a problem to the DSG for April 2019.

THE PROBLEM GIVEN TO THE DSG When children are on life-support, their vital signs are monitored continuously. Clinical staff make treatment decisions informed by current snapshots of these signs. The challenge was to develop predictive algorithms that out-perform clinical decision-making for one high-risk decision faced for every patient: optimal timing for a trial of breathing without life-support.

THIS TALK I am an Operational Researcher and will discuss how I worked closely with GOSH and others to conceive of, negotiate, plan, execute and interpret the hospital's foray into new data science. I will discuss the skills needed, the challenges encountered and the preliminary results.

4 - Blockchain in food distribution: do you know where your food has been?
Dan Bumblauskas, Brett Dugan, Jacy Rittmer

This paper aims to explain the implementation of blockchain technology in the production and supply chain delivery system for beef/cattle by a company based in the USA (Bytable Foods). One of the primary research questions is how blockchain can more accurately and transparently move goods through supply chains. This company, and paper, are at the leading edge of developing such systems in industry. Bytable Foods has various initiatives in development on the front line of blockchain. Bytable Foods is making food traceable and transparent through trustworthy data chains that track products from farm to fork using blockchain technology and internet of things. By creating traceable and transparent supply chains for food, consumers are given the information they need to make the right choice about the food they buy and the companies they support. For stakeholders in the food supply chain, having traceability and transparency builds better relationships with their customers, increases efficiency, and reduces the risk and cost of food recalls, fraud, and product loss. The technology and business are creating a case for fixing and transforming the world's food system. One case study of interest in the academic and industry community is related to the cattle industry. Bytable was founded in Iowa and is based in Colorado while IBM is working on a similar application called Beefchain.

■ TB-04

Tuesday, 10:30-12:00 - Q116

Teaching OR/MS 2

Stream: OR Education
Invited session
Chair: Milagros Baldemor

1 - Activities in OR course to teach TSP and CVRP.
Carlos Olivos, Evelyn Arrey, Hernan Caceres

The Traveling Salesman Problem (TSP) and its extensions of capacitated vehicle routing problem (CVRP) are one of the most famous problems that exist in the literature of operations research. Given its popularity, we propose two educational activities to teach these problems to industrial engineering students in the operations research course at Universidad Católica del Norte, Antofagasta, Chile. To teach the TSP, we use materials such as yarn, drawing pins and a cork board. Students must first locate random points on the board to represent the cities that should be visited. With the thread they must determine the tour, trying to use as little as possible. With this activity students learn and become familiar with this classic problem, understanding the combinatorial complexity that exists, advantages and disadvantages of using the heuristic of the nearest neighbor. In the case of the CVRP, students must represent the vehicle with capacity and the clients that must be satisfied. The vehicle will have a capacity, and the demand of the customers is deterministic. The teams must determine the best routes to follow in order to meet the demand at the lowest cost. They have a planning time before starting the activity. Finally, students compare their represented solution and the solution obtained through the optimizer for both problems. Both activities with photos and videos will be presented to show the results of this methodology.

2 - Cost Minimization: Differential Calculus Approach VS Weighted Arithmetic Mean - Geometric Mean Inequality Approach
Vedran Kojić, Zrinka Lukač, Mira Krpan

One of the basic lessons taught in the 1st year of studying economics is minimizing economic costs. The standard way of solving this problem is to apply differential calculus. The process includes understanding, computing and applying derivatives. Here most of the 1st year students encounter calculus for the first time. Since it is unfamiliar to them, many of them are not keen on it, resulting in poor knowledge of optimization as well. In this paper we explore an alternative approach to solving optimization problems, specifically the problem of minimizing economic costs. One of the ways to solve it is the application of weighted inequality between the arithmetic and geometric mean (WAG inequality). Since WAG is transparent and intuitive, it can be taught without any formal foreknowledge. In order to determine which approach is easier for students when dealing with optimization problems in economics, we have presented both the WAG and differential calculus approach to cost minimization problems to a group of 1st year economics students within the compulsory Mathematics course. The results show that students found the WAG method easier to understand and use when solving the above mentioned problems. Although we cannot say that WAG approach is generally better than differential calculus approach, it is quite certain that WAG is a good introductory method that can help students understand and adopt the more complex terms and procedures required by the differential calculus.

3 - Teaching Optimization Algorithms

John Chinneck

The correct application of computational algorithms for optimization requires a fundamental intuitive understanding of how they work. This provides insight into the kinds of problems that can be tackled, the kinds of results that can be expected, and an understanding of how to detect and make sense of erroneous or misleading results. It also permits students to see how methods can be combined or modified to solve non-standard problems. Based on 33 years of teaching introductory optimization to both graduate and undergraduate engineering students, I have developed an approach to teaching optimization algorithms that relies on 3 main elements: • Clear presentation of algorithms via diagrams and examples in an online textbook. • Online algorithm animations • Labs and homework that exercise the algorithms, both by hand and by use of solver software. Exercises are mini-cases that require formulation, algorithm selection, algorithm execution, and results report. The expository principles are (i) explanation and diagrams are more effective in transmitting understanding than a total reliance on mathematics, and (ii) there should be exposure to how things are done in practice, which can be significantly different than in the classroom. The course web site is open, including the online textbook and algorithm animations, and is available at http://www.sce.carleton.ca/faculty/chinneck/po.html. The website is used in a number of university courses worldwide.

4 - Collaborative Learning Strategy in Enhancing the Analytical Performance of Tertiary Students in Calculus IIIIII

Milagros Baldemor

This study determined the degree of performance enhancement of the second year Bachelor of Science in Mathematics students enrolled in Calculus III during the first semester of school year 2016-2017 using the collaborative learning strategy together with anticipation-reaction guide particularly in the use of the different integration formulas and its applications. Furthermore, it determined the profile of the respondents as to learning styles, attitude towards the subject and previous grades in lower Calculus. It employed the pretest-posttest experimental design using two equivalent groups: the experimental group exposed to the collaborative learning strategy and anticipation -reaction guide and the control group exposed to the conventional teaching method. The difference in the pretest-posttest scores and their performance in the formative activities and the relationship between their profile and performance were also determined. Findings showed differences in their learning styles and attitudes towards the subject. Significant difference was reflected in the pretest and posttest scores of both groups and also their posttest scores and the results of their formative activities. In addition, there was no significant relationship between their learning styles and attitude to their performance but a significant relationship was posted between their performance and their previous grades in lower Calculus.

■ TB-05

Tuesday, 10:30-12:00 - A003

Behavioural Aspects in Spatial Decisions

Stream: Decision Analysis

Invited session

Chair: *Valentina Ferretti*

1 - Spatial multi-attribute decision analysis with attribute specific spatial weights and incomplete preference information

Mikko Harju, Juuso Liesiö, Kai Virtanen

In spatial decision problems, consequences of alternatives vary across a geographical region and are measured by multiple attributes. Such spatial problems are difficult to tackle adequately by conventional decision analysis techniques and models. We present necessary and sufficient conditions for representing preferences among spatial decision alternatives with a multi-attribute additive spatial value function. The value function is based on aggregating consequences, both spatially and attribute-wise. Furthermore, the function does not require the importance of attributes to be constant across the spatial region. Determining the value function is challenging, however, as it requires assigning an infinite number of spatial weights representing the relative importance of subregions with respect to each attribute. To overcome this challenge, we present a decision analysis method for capturing incomplete preference information on attribute and spatial weights as well as for identifying the resulting dominance relations among the decision alternatives. Thus, the method allows for the computation of the non-dominated decision alternatives. The potentially optimal alternatives can also be identified in certain cases. We demonstrate the use of the new value function and the method with an application in military planning.

2 - A Bayesian framework for spatial risk assessment: an application to oil tankers

Matteo Spada, Valentina Ferretti

Quantitative risk assessment supports decision-making processes in an increasing variety of contexts. Within the domain of environmental decision-making, the spatial distribution of impacts, vulnerabilities and consequences associated to different risk-mitigation alternatives calls for an integrated approach able to combine decision analysis under uncertainty with geographic information science and behavioral insights. In this talk, we propose the combined use of a hierarchical Bayesian modelling approach with Geographic Information Systems and multi criteria analysis to integrate uncertainty and model probabilities into an overall risk map. The research aims at testing the operability of the integration between Bayesian modelling and spatial analysis in the context of spatial risk analysis processes for resource allocation. To this end, we tested the model on a case study dealing with tanker oil spill risk in the Mediterranean Sea. We conclude by discussing the implications from the process and behavioral point of view of the proposed framework. The innovative contribution of the study stems from both the context of application point of view and the use of Bayesian modelling to calculate not only probabilities but an overall spatial risk measure.

3 - Map-based choice architecture

Valentina Ferretti, Yesmean Luk

Scientific research has demonstrated that subjective values are highly sensitive to the presence or absence of a stimulus (i.e., a change from zero to some number), but are largely insensitive to further variations in scope. This phenomenon is known as scope insensitivity and is a cognitive bias with relevant implications for both policy making and management. While a significant body of literature discussing the presence of this bias and its implications across different domains already exists, very few studies have explored the spatial dimension of scope insensitivity, as well as ways of reducing its effects. This paper is part of an ongoing research program aiming to investigate the impacts associated to the use of geographical maps on spatial scope insensitivity. Are geographical maps enhancing the bias, mitigating it or not affecting it? This contribution explores the answer to the above research question by developing a behavioural laboratory experiment on map-mediated willingness to pay for the remediation of certain environmental areas.

4 - Selecting an effective preventive program for university lecturers' vocal health

María Jesús Rufo Bazaga, Jacinto Martín, Carlos Javier Pérez Sánchez

An important clinical issue is related to find appropriate treatments for voice disorders, such as vocal fold nodules. They are often caused by vocal abuse or misuse, and their incidence is higher in occupations that require frequent voice use. Therefore, the economic costs derived from sick leaves in those professions could be reduced by applying prevention programs based on noninvasive and low cost tools. This work presents a Bayesian decision approach based on acoustic features that allows an automatic classification of university lecturers according to three different treatments related to three voice risk groups (low, medium and high). The considered decision process takes into account the posterior probabilities of developing vocal disorder and the utility functions that include different criteria such as the utility of recovery and the cost of the treatments. Then, a simulation-based approach is implemented in order to maximize the expected utilities for each university lecturer. Under the more realistic assumption of a fixed budget provided by the corresponding Department, a preventive program is considered. Specifically, a 0-1 integer linear programming problem is formulated. It involves constraints that include both the costs for the different treatments and the available budget. An application for university lecturers from the University of Extremadura is presented and discussed in order to show that the proposed techniques are easily applied in practice.

■ TB-06

Tuesday, 10:30-12:00 - A004

Modelling Platforms and High Performance Computing

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Juha Kiviluoma

1 - Design decisions for a modelling platform
Juha Kiviluoma

A modelling platform can provide several benefits for a modelling community in comparison to ad-hoc maintenance of data, tools and scenarios. First, modelling large scale systems often requires data from multiple sources with various transformation before use. A modelling platform can help to document the data trail and offer replicability to the data processing chains. Second, the same data could potentially serve multiple tools and models. However, it would be laborious to build data interfaces between each possible tool. A modelling platform should therefore offer a generic data format that allows to more efficiently connect a family of tools and models while also enabling a common interface to all data in the system. Third, future is uncertain and the uncertainty needs to be charted with a sufficient sample of possible futures. Consequently, modelling typically entails managing several scenarios and it would often be recommendable to have a wide range of them. Managing and executing a large number of scenarios can become disorganized unless there is a way to keep track what has been done - documenting both data and model versions. A large number of scenarios can also lead to a large computational effort, which nowadays could be effectively executed in the cloud as long as the platform allows that. This presentation will demonstrate the design decisions we have taken to tackle these issues when developing the Spine Toolbox.

2 - Generic data structure design and data exchange for a modelling platform
Fabiano Pallonetto

An essential requirement for a flexible modelling platform is a robust and simplified mechanism to exchange data between modelling tools. It is also convenient having specific features to view and share data across the platform models. We, in the EU project Spine, have designed such a framework and are currently developing interfaces to shared data sources and modelling languages. We aim to enable partially automated data ingestion and processing for both input and output data, enabling users to focus on core modelling tasks. The open source software suite includes an entity-relationship data infrastructure for the model parameters, constraint definitions and data repository. This data structure is highly generic and can adapt to serve many different kinds of models and tools. We are working to enable a smooth data transfer from the databases into modelling languages like Julia and thereby enabling the modellers to manage their data efficiently with a unified tool to access the data at the model side. The data structure is designed to store parameters of different systems that consist of objects, their relationships and their properties, e.g. hydro turbines or economic actors. Such flexibility allows the integration of different analysis in a common modelling framework which can combine the output of heterogeneous perspectives at different resolutions. The combined models can provide unique insights and original results for the systems modelling research community.

3 - Paving the Path Toward Large-Scale Applications of Nodal Pricing Models: Distributed Computing of ELMOD with a Parallel Interior-Point Solution Solver
Hannes Hobbie, David Schönheit

In the analysis of electricity markets a distinction between zonal and nodal pricing market designs can be drawn. In zonal pricing markets the clearing operator determines only the optimal economic power plant dispatch, which usually entails a redispatch of awarded capacities due to ensuing grid congestions. Conversely, nodal pricing includes transmission constraints already at the stage of market clearing to avoid redispatch activities. Model-based representations of nodal pricing markets likely become large-scale due to the inclusion of the entire high voltage grid, detailed technical modelling of generation units and a highly-resolved time dimension to represent local diurnal and seasonal variations of renewable feed-in and electricity demand. To simplify the high degree of complexity, state-of-the-art conceptual speed-up techniques are often applied, such as rolling horizon approaches and time aggregation. This ground-breaking work builds upon innovative distributed computing of the nodal pricing model ELMOD, enabled by a parallel interior-point solution solver, which renders unnecessary simplifications through conceptual speed-up techniques. The model is solved using 8760 hours and considers most European countries, encompassing 3329 nodes and 7183 generating units. The results will comprise a detailed discussion of the obtained insights and will give an outlook for future applications to assist policy makers and stakeholders in an efficient electricity market design.

4 - Application and performance evaluation of a parallel solver for energy system models with high spatial and temporal resolution
Manuel Wetzel

The increasing complexity of optimizing energy system models to answer research questions in more and more detail is one of the main drivers towards high performance computing. One of the current limitations is solving these large scale optimization problems with respect to memory constraints and a reasonable wall-clock time. The open source solver PIPS-IPM addresses this problem by providing access to distributed memory architectures and exploiting the block structure of the mathematical optimization problems. Application of PIPS-IPM requires additional information about the underlying block structure of the energy system model which is provided via model annotation based on the expert knowledge of the modeller. Further development of the PIPS-IPM solver and application to several optimizing energy system models are one of the key achievements of the BEAM-ME project. This required bringing together interdisciplinary expertise from the fields of energy systems analysis, mathematics, operations research, and informatics in order to establish efficient solution strategies for complex energy system models. This talk addresses the necessary steps of bringing the energy system model REMix to high performance computers and utilizing the parallel interior-point solver PIPS-IPM. Furthermore the performance of the solver is compared for several high spatial and temporal model instances and different types of decomposition.

■ TB-07

Tuesday, 10:30-12:00 - A007

OR in Forestry I

Stream: OR in Agriculture and Forestry
Invited session
Chair: Lidija Zadnik Stirn

1 - Forest ecosystem management - an integrated bio-economic approach in Portugal.
Liliana Ferreira, Miguel Constantino, Susete Marques, Brigite Botequim, Jose Borges

The forest sector plays a key role in the Portuguese economy and society. Nevertheless, lack of active management is still a serious obstacle to its development. After the catastrophic wildfires in 2017, it became evident that alternative forest management should be explored. Ecosystem management planning, policy analysis and payment for ecosystems services demand for innovative decision support tools and represent a challenge to researchers and stakeholders. This research aims at presenting an integrated approach to forest ecosystem management planning that provides indicators, estimates and policy analysis of trade-offs between forest-based products and services provided by the forest, such as products measured per ha (e.g. timber, pine cones, carbon and cork) or services that depend on the spatial distribution of management options (e.g. biodiversity and wildfires resistance). The case study area includes Zonas de Intervenção Florestal de Paiva and de Entre-Douro e Sousa which is located in northwestern Portugal, 100 km from Oporto in a rural area with a Mediterranean climate with an Atlantic influence.

2 - A sequentially multi-criteria model to identify multi-level conflicts in protected areas
Monica de Castro-Pardo, Fernando Pérez-Rodríguez, José María Martín Martín, Joao C. Azevedo

Participative multi-criteria methods are carried out efficiently in protected-areas' planning processes in order to reduce conflicts and formalize the stakeholders' participation in the decision-making processes. In this paper, we propose a sequentially participative model for the planning of protected areas based on the Analytical Hierarchy Process, Goal Programming and Monte Carlo simulation. The model has been developed in two scenarios: one determinist and another one built with simulations and provides a multi-level ranking of the most relevant management goals according to the stakeholders' preferences that seek to establish the priorities in the planning of a protected area. Moreover, the model allows for the identification of conflicts, providing a comparison amongst the most likely priority and the most consistent groupal priority, associated with each management goal. The model was tested in a Portuguese-Spanish Reserve: Meseta Ibérica. The results showed that the main objectives for this area are related to conservation and development in first level, agroforestry, fauna and flora in the second level, and wildlife preservation, certification of local products and prevention of fires in the third level. The greatest conflicts are related to conservation, agroforestry, local development, prevention of fire, wildlife conservation and certification of local products.

3 - Economic analysis comparing the artificial Cryptomeria japonica forest management and the installation of mega-solar power generation
Shizu Itaka, Masashi Konoshima

Solar power generation has been gaining increasing interest as a renewable energy resource and its technology has been dramatically improving. However, in Japan, the recent increase in incidents of turning a forest into a mega-solar power generation with more than 1MW capacity has raised significant concern because it degrades forest ecosystem services. In the aim of quantifying the potential forest ecosystem services maintained if forest areas were set aside and managed for timber and woody biomass production, we evaluated the opportunity cost of maintaining forest ecosystem. We evaluated both the net present value (NPV) and the amount of power-supply from a mega-solar power generation and a woody biomass power generation that uses wood chips sourced from managed forests. We, then, compared the introduction of a mega-solar power generation and a forest management in terms of both NPV and the amount of power-supply. The estimation of NPV and power supply from woody biomass is based on the optimal forest management strategy generated from dynamic programming model. We found out that the amount of power-supply from a mega-solar power generation was about 70 times more than that of woody biomass. Also our results show that a mega-solar power generation provides about 90 times more NPV than from forest management. This study is the first attempt to estimate the opportunity cost of maintaining forest ecosystem using both monetary and non-monetary terms. This difference provides th

4 - Some extensions in AHP for multivariate, group and fuzzy management of (forest) ecosystems
Lidija Zadnik Stirn, Petra Grošelj

Most of the innovative models, also OR oriented, are not forestry and rural areas-specific, and are mainly not focusing on forest-dependent communities. We address this gap by generating a multi-criteria model based on some extensions of classical AHP. Wide-ranging criteria and objectives and different viewpoints of stakeholders, who are included in decision process, are captured within group AHP. Our approach extends the crisp group judgments into interval group judgments or/and into triangular fuzzy numbers (TFN) judgments. Imprecision and vagueness in data are handled by representing individual judgments with interval judgments or with TFNs. For aggregating the individual interval judgments into group interval judgments a consensus method based on the importance of decision makers and the width of the interval weights is proposed. Further, for aggregating the individual TFN judgments into the group TFN judgments we advise a soft consensus method. The model can measure and rank decisions in management of environmental systems. It was applied to assess the SWOT factors which influence the development of Pohorje, a protected forest/rural area in Slovenia. The results show that sustainable development with goals to preserve cultural heritage, local tradition and nature, to use renewable resources in environment and consumer friendly way, to increase the quality of life for locals, and to develop sustainable tourism with limited number of visitors, gained a highest rank.

■ TB-08

Tuesday, 10:30-12:00 - A008

Disaster Management

Stream: OR in Humanitarian Applications
Invited session
Chair: Denis Olschok

1 - Simulation Modeling and Analysis of a Mass Casualty Transportation System for Disaster Response
Sule Itir Satoglu, Nadide Caglayan

Design of a casualty transportation system is crucial, for a better response to the severe disasters. In this study, an experimental design is made for the casualty transportation system, to determine the most important design factors, and a simulation-based modeling and statistical analysis are performed. The experimental factors are patient-transferring to the hospitals according to triage (all patients or severe patients forwarded to the hospitals); hospital selection rules (closest hospital or the one with highest available capacity); number of ambulances, and casualty prioritization according to the RPM score. Hence, sixteen scenarios are generated. Later, the simulations models are constructed. The real data of Kartal district of Istanbul city is used including the real hospital-demand point distances and hospital capacities. The model of each scenario is run for ten replications. Time elapsed since the evacuation of the patient until delivery to the hospital is measured in the simulation models, as a performance criterion. To statistically interpret the results and to determine main effects and the interaction effects, the Factor Analysis is applied to the simulation output. All of the main effects and some of the two-way and three-way interaction effects are found statistically significant.

2 - The Hazmat u-Interdiction median problem with fortification in urban areas to face NATECH events
Andrés Bronfman, Pamela P. Alvarez, Natalia Sepúlveda

Hazmat release accidents from hazardous institutions and during hazmat transportation are attributed to a variety of causes, such as defective equipment, damaged materials, or operator and driver error. However, there are other sources that may trigger hazmat release, such as natural disasters. These events, known as "Natech" (Natural Hazard Triggering Technological Disasters), involve the release of a hazardous material as a result of a natural disaster, such as a hurricane or earthquake. These events present characteristics that differentiate them from other types of hazmat release accidents: (i) many hazardous facilities and shipments may be affected simultaneously in the area affected by the natural disaster; (ii) cascading disasters may occur (domino effects), in which the release of an active hazardous material triggers another. To address this problem, we formulate and solve the Hazmat u-Interdiction median problem with fortification as a bi-level problem. In the first level, we identify the unprotected hazardous facilities that in the event of a natural disaster would generate maximum exposure danger for the population. Meanwhile, in the second level, we identify which facilities to strengthen, so as to minimize the exposure danger to the population. Finally, the methodology is applied in a real case for the city of Santiago, Chile.

3 - Simultaneous Planning for Disaster Road Clearance and Distribution of Relief Goods: A basic model and an exact solution method
Denis Olschok, Alf Kimms, Dirk Briskorn

In recent years more and more natural and man-made disasters occurred. Additionally, the amount of people affected by disasters is increasing. Not least because of this it is of great importance to arrange the relief operations efficiently in order to alleviate the suffering of the disaster victims. Immediately after the occurrence of a disaster there is an urgent need for delivery of relief goods to demand points and affected regions, respectively. Due to blocked or damaged roads by disaster debris some demand points may be cut-off in the road network and therefore the delivery of relief goods is hampered. This study investigates the basic problem of simultaneously detecting roads to unblock in order to make demand points accessible and determining specific deliveries of relief goods in order to satisfy the demands up to their individual due dates. A mixed-integer programming model is proposed to solve this problem. Moreover, an exact solution method based on a branch-and-bound approach is developed and a computational study is conducted.

4 - To print or not to print: The two stage stochastic knapsack 3D-printing problem
Loe Schlicher, Denise Tönissen

Inspired by humanitarian relief operations, we study a new type of knapsack problem, which we call the two-stage stochastic 3D-printing knapsack problem. In the first stage of this problem, a decision maker has to fill a certain number of knapsacks, with the special consideration of taking a 3D-printer with an associated amount of printing material, or not. Then, in the second stage, demand is revealed, according to an underlying probability distribution, and the physically brought items that match demand are allocated. If a 3D-printer is taken, the next consideration is how to use the printing material for the remaining demand. Meeting demand, via a physically brought item or a printed item, results in an item-specific reward, which may depend on its nature (i.e., whether it is printed or not). Aim is to make, a priori, a decision upon the number of physical items to take, whether to bring a 3D printer or not, the amount of printing material to take, and how to use it, in order to maximize the expected total reward. In this talk, we will shed light on the trade-off of bringing a 3D-printer or not (and which amount of printing material to take) and to which extend this problem is computationally hard to solve.

■ TB-09

Tuesday, 10:30-12:00 - B006

DEA applications to Sustainability and Development

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Chris Tofallis

1 - A Longitudinal Analysis of the Social Performance of Mining Firms
Ana Camanho, Renata Oliveira, Andreia Zanella

This paper is focused on the evaluation of social performance of mining firms using quantifiable criteria, examining in detail the social dimension of Corporate Social Responsibility. The developments proposed in this paper include a framework for the specification of indicators reflecting social burdens and benefits associated with mining firms' activity, based on international standards and sectorial guidelines. Reputation issues associated with firms' impact on society, including local employment and contribution to local economic development are nowadays considered critical, so the definition of appropriate key performance indicators to address this subject is an important contribution to the literature. This study uses a composite indicator, formulated with a Directional Distance Function, to evaluate social performance. It can be used both for benchmarking comparisons among firms within an industry and to monitor the evolution of performance over time. This study proposes new formulations of the Malmquist index that can be used with composite indicators estimated with particular directional vectors. The formulation of the composite indicator proposed in this paper overcomes the widely reported problems of infeasibilities associated with estimates of productivity change over time based on directional distance functions. An illustrative application involving the assessment of 24 large mining firms in the years 2011 and 2012 is discussed

2 - Performance evaluation under "Zero-Waste" strategy: evidence on waste management in Tuscan municipalities
Laura Carosi, Giovanna D'Inverno, Giulia Romano

Recent empirical studies support the idea that the principles underpinning the zero-waste strategy are effective for reducing waste production and increasing the recycling rate (Connett, 2013; Xevgenos et al., 2015, Zaman, 2015). According to Connett (2013), there are 10 steps toward the implementation of a zero-waste strategy, among which door-to-door collection systems, recycling and waste reduction programs and Pay-As-You-Throw taxes, along with the introduction of economic incentives. The performance of urban waste management of Tuscan municipalities is studied with a specific attention on cost of waste collection and treatment. As several Tuscan municipalities formally adopted the zero-waste strategy, the current study aims at investigating how this political choice affects the overall performance evaluation of urban waste management at municipal level. Data about Tuscan municipalities were retrieved from many different sources: the Italian National Institute of Statistic (ISTAT), the Italian Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), the Tuscan regional agency, Agenzia Regionale Recupero Risorse S.p.a. (ARRR), and the Zero Waste Research Center located in Capannori, Italy.

3 - Applying a Malmquist-Luenberger Index Approach to Evaluate Urban Sustainability at the Borough Level: A Case Study of London, England
Sadiye Sadanoglu

Assessing sustainability performance is a major challenge for many cities in the world. Performance evaluation of urban sustainability has a vital impact on improving urban well-being, while also balancing the demands of urban social and economic development, natural resource consumption and environmental pollution. This paper provides a comprehensive framework for simultaneously evaluating urban sustainability from three perspectives: economic, environmental and social. We assess the urban sustainability of 32 boroughs in London from 2012 to 2015 with the aim of identifying the best practices of and the lessons learned by the borough councils. Given the performance measures constituting both desirable and undesirable outputs and dynamic changes, the Malmquist-Luenberger Index (MLI) approach is applied. The results indicate that: (1) Twenty-five percent of the boroughs showed productivity growth over the three-year period. (2) Reducing energy consumption has a significant, positive effect on sustainability, while density, industrialisation and deprivation have a negative effect. The geographic spread of boroughs also affects performance. (3) The power of politics and finance play a critical role in overall performance. This research takes a novel approach in studying urban sustainability at the borough level to determine how local authorities contribute to overall urban sustainability.

4 - Which formula for national happiness?
Chris Tofallis

The World Happiness Report is published by the United Nations Sustainable Development Solutions Network and contains an international ranking of national average happiness, as measured by surveys of personal life evaluations. It also contains an analysis which tries to explain the happiness figures from more than 150 countries using data on six key variables. That analysis assumes the factors combine in an additive manner and therefore operate independently of each other. By contrast, we explore a multiplicative model, which allows for interactivity or synergy between factors, as well as the possibility of diminishing marginal benefit at higher levels of achievement. We find that this model provides a better fit to the data and is therefore superior in its explanatory power. The implication for policy-makers is that they should focus on improving those factors which are the lowest for their nation as this will provide greater relative benefits to subjective well-being. At an individual level this means focusing on improving conditions for those who are experiencing the lowest levels of well-being.

■ TB-10

Tuesday, 10:30-12:00 - H0.12

Polynomial optimization

Stream: Copositive and Conic Optimization
Invited session
Chair: *Georgina Hall*

1 - On exact polynomial optimization through sums of squares, sums of nonnegative circuits and sums of arithmetic-geometric-mean-exponentials
Victor Magron

We consider the problem of certifying nonnegativity for certain classes of multivariate polynomials. We focus on finding exact sums of squares (SOS), sums of nonnegative circuits (SONC) and sums of arithmetic-geometric-mean-exponentials (SAGE) decompositions. For each case, we rely on existing relaxations: semidefinite programming (SDP) for SOS decompositions, geometric programming (GP) for SONC decompositions and relative entropy programming (REP) for SAGE decompositions.

For the SOS case, we provide a hybrid numeric-symbolic algorithm computing exact rational decompositions for polynomials lying in the interior of the SOS cone. It computes an approximate SOS decomposition for a perturbation of the input polynomial with an arbitrary-precision SDP solver. An exact SOS decomposition is obtained thanks to the perturbation terms. We provide two hybrid numeric-symbolic algorithms, computing exact rational decompositions for polynomials lying in the interior of the SONC and SAGE cones. Each framework, inspired by previous contributions of Parrilo and Peyrl, is a rounding-projection procedure.

We prove that the three algorithms terminate within a number of arithmetic operations, which is polynomial in the degree of the input polynomial and its number of terms, and simply exponential in the number of variables. We also provide experimental comparisons between the implementation of these algorithms and available alternatives.

2 - Iterative LP and SOCP-based approximations to semidefinite and sum of squares programs
Georgina Hall

We develop techniques for approximating SDPs (and hence sum of squares programs) with LPs and SOCPs. Our algorithms iteratively grow an inner approximation to the PSD cone using a column generation scheme and/or a change of basis scheme involving Cholesky decompositions.

3 - A class of adaptive discretization methods solving semi-infinite programming problems (SIPs) with quadratic rate of convergence
Tobias Seidel, Karl-Heinz Küfer

Semi-infinite programming can be used to model a large variety of complex optimization problems. In particular, cutting and packing or coverage problems formulated with geometric constraints like subset and separation conditions are interesting applications. Unfortunately, the simple description of the problems has its price. A semi-infinite problem is often harder to solve than a finite non-linear problem. Nevertheless different strategies have been developed to solve these problems. A classic approach, which is easy to implement, is based on discretizing the semi-infinite index set. Therefore a sequence of finite problems resulting from increasingly fine discretizations of the index sets is solved. Convergence rates based on the mesh-distance of the discretization are well known. However, one can observe in practice that for many problems convergence can be improved by adding the solutions of the lower level problems to the discretization. To the best of our knowledge theoretical results supporting this observation have not been reported in the literature so far. In this talk, we will present results proving a quadratic rate of convergence for an adaptive discretization algorithm, which explains the improved convergence properties. Besides the theoretical concepts the talk will address several domains of applications the Fraunhofer Institute for Industrial Mathematics is working on. Examples are gemstone exploitation, pump portfolio optimization and robust optimization.

■ TB-11

Tuesday, 10:30-12:00 - H1.12

Projection algorithms

Stream: Nonlinear Programming. Theory and Methods
Invited session
Chair: *Rubén Campoy*
Chair: *Francisco Javier Aragón Artacho*

1 - Finitely Convergent Projection Methods
Rafal Zalas

In this talk we propose a finitely convergent method for solving the convex feasibility problem. Following other works in this area, for example, by Polyak (2001) and more recently, by Bauschcke et al. (2015), we assume that the interior of the solution set is nonempty and that certain parameters form a divergent series. Due to the infinite pool of operators (cutters) that we allow in our method, we introduce a new cardinality condition which holds naturally for many known projection and subgradient projection methods as we demonstrate in this talk. In particular, it is satisfied for methods governed by cyclic, almost cyclic and even repetitive controls. Moreover, it is almost surely satisfied for random controls. This is a joint work with Victor Kolobov and Simeon Reich.

2 - Performance Estimation in Operator Splitting Methods
Pontus Giselsson

We propose a methodology for studying the performance of common operator splitting methods through semidefinite programming. We prove tightness of the methodology, meaning that the semidefinite program is guaranteed to exactly capture the worst case behavior of the studied splitting method. We demonstrate the value of the approach by using it as a tool for computer-assisted proofs to prove tight analytical contraction factors for Douglas–Rachford splitting that are likely too complicated to find bare-handed.

3 - Two parallel variants of the averaged alternating modified reflections method for best approximation problems
Rubén Campoy, *Francisco Javier Aragón Artacho*

In this talk we present a new iterative projection method. This method, termed AAMR for averaged alternating modified reflections method, can be viewed as an adequate modification of the Douglas-Rachford algorithm that yields a solution to the best approximation problem. We show how the scheme can be generalized so that it can deal with monotone operators. Based on this, together with a standard product space reformulation, we propose two parallel variants of such splitting method. We illustrate and compare both of them for solving best approximation problems described by finitely many sets.

■ TB-12

Tuesday, 10:30-12:00 - H1.51

Recent Innovations in Combinatorial Optimization

Stream: Combinatorial Optimization I
Invited session
Chair: *Fred Glover*

1 - Exploring properties of combining solutions of the Boolean optimization problem
Lars Magnus Hvattum, *Rodrigo Ferreira da Silva*, *Fred Glover*

The Boolean optimization problem (BOOP) generalizes the satisfiability problem by introducing an objective function consisting of a weighted sum of the variables that are set to true. This means that many important optimization problems can be formulated as BOOPs, such as weighted versions of set covering, graph stability, set partitioning, and maximum satisfiability. The previously best results for solving the BOOP was obtained by a relatively simple tabu search. This work examines the use of a set of solutions, each found using tabu search, and how these solutions can be combined into new solutions and further improved by the tabu search. First, it is shown that combining solutions can lead to a search space that can be decomposed. Second, it is demonstrated that it is beneficial to combine more than just two solutions at a time, as in early tabu search proposals associated with scatter search and path relinking.

2 - Optimizing industrial process by clustering. Relation with coloring and clique problems in graphs
Joaquín Pacheco, *Manuel Laguna*, *Silvia Casado*, *Julio Cesar Puche*

Manufacturing of steel coils is an example of a industrial process. First, the raw materials (iron ore, and other minerals) are extracted. These minerals are combined to produce steel, which through continuous casting is shaped as steel slabs. A strip mill turns the slabs into cold roll coils. The optimization of a production process for steel coil depends on the utilization of the production facility and equipment. We study the production of steel coils and we exploit the efficiencies from grouping products with similar characteristics. While it is simple to establish a one-to-one correspondence between an industrial and a final product, there are several advantages associated with producing in a setting where the relationship between industrial and final products is one-to-many. These advantages include reduction of the labor needed to adjust the equipment. To create one-to-many mappings of industrial products to final products, it is necessary to grouping the final products based on a set of relevant attributes (width, weight, steel grade). We formulate the grouping problem as a mixed-integer program and develop a heuristic solution procedure. We show that a simplified version of the problem is equivalent to the clique partition problem. Our heuristic method is based on tabu search combined with multi-start framework. Computational experiments show that the heuristic procedure find high-quality solutions to both the clique-partitioning problem and our grouping problem.

3 - Scheduling container storage operations of two non-passing stacking cranes
Erwin Pesch, *Mikhail Y. Kovalyov*, *Andrew Ryzhikov*

We consider a container block, in which there are incoming containers to be stacked by two non-passing cranes based at the opposite sides of the container block. Containers are assigned to the cranes according to one of the following policies: (1) two fixed sequences policy where a container processing sequence is given for each crane, (2) dedicated crane policy where containers are preassigned to the cranes, (3) one fixed, one arbitrary sequence policy where a container processing sequence is given for one crane and it can be arbitrary for the other crane, (4) flexible policy where any container can be assigned to any crane at any time, and (5) global fixed sequence policy where the container sequence is given and the relative processing order of containers in this sequence must be preserved by any crane. The objective is to minimize the completion time of the latest operation. We show that the problem is polynomially solvable for policy 1 and, if the number of containers to be placed in the same bay is no more than a half of all containers, for policy 4. It is NP-hard in the strong sense for policies 2 and 3. Approximation algorithms with guaranteed absolute and relative deviations from the optimum are devised for policies 4 and 5. The results translate for the case of outgoing containers only.

■ TB-13

Tuesday, 10:30-12:00 - H2.12

Inverse Optimization

Stream: Inverse Optimization
Invited session
Chair: *Daria Terekhov*
Chair: *Daria Terekhov*
Chair: *Daria Terekhov*

1 - A fast algorithm to estimate the cost and the right-hand side parameter vectors in inverse linear optimization
Juan Miguel Morales, *Ricardo Fernandez-Blanco*, *Salvador Pineda Morente*

In this presentation, we deal with the problem of estimating the cost and right-hand side parameter vectors of a linear optimization problem from a series of observed optimal solutions. For this purpose, we propose a two-step estimation procedure that consists in sequentially solving two linear programs, namely, a feasibility problem whereby the right-hand side vector is first computed, followed by an optimality problem that delivers the cost vector. The feasibility problem relies on a hyper-parameter that is tuned via cross-validation. We show numerically that the proposed estimation procedure, besides computationally inexpensive, is statistically consistent. Indeed, given enough information, the procedure is able to recover the true cost and right-hand side parameter vectors of the underlying linear optimization problem. Furthermore, this holds even in cases where the cost and right-hand side parameter vectors are linear functions of a set of regressors. We illustrate our claims on realistic applications of the proposed inverse optimization framework.

2 - Learning Parametric Convex Programs From Optimal Decisions

Daria Terekhov, Elaheh H. Iraj

We study the inverse optimization problem of imputing objective function coefficients of a convex parametric optimization problem from past optimal or near-optimal decisions. We view this problem as a machine learning problem where targets are generated by an optimization process. In this work, we empirically compare the performance of standard machine learning (ML) algorithms, namely random forest, support vector regression and Gaussian process, to the performance of a specialized inverse optimization (IO) algorithm. To the best of our knowledge, this is the first study to apply classical ML approaches to an IO problem and to compare their performance with that of a specialized IO algorithm. We show that IO is more data efficient than classical ML approaches, but that its performance is more sensitive to the degree of correctness of prior information. Furthermore, we show that, with a large data set, some IO problems can be well-solved using out-of-the-box ML methods.

3 - Preconditioning Linear Systems Arising from Interior Point Methods

Aurelio Oliveira, Carla Ghidini

The development of sophisticated software for solving linear programming problems using interior point methods have started since the early works. There are at least three main research lines aimed to improve the efficiency of such methods for solving large-scale problems: the reduction of the total number of iterations; implementation techniques to obtain fast iterations; and specific methods for particular classes of problems. This work deals with the second research line. Iterative methods are used to solve the linear systems, the most expensive step of interior point methods, mainly when computing the Cholesky factorization is prohibitive due to time and memory requirements. Special attention is given for preconditioning the linear systems. Since such systems are highly ill-conditioned near a linear programming problem solution, the design of specially tailored preconditioners is an imperative implementation issue. On the other hand, a more general preconditioner fits better at early iterations where the linear system features are very different in comparison with the ones presented in the last iterations. Some hybrid preconditioning strategies, combining the controlled Cholesky factorization and the splitting preconditioner are presented. Numerical experiments with public available large-scale linear programming problems are performed showing the efficiency of the preconditioned iterative approaches.

4 - Deep Inverse Optimization

Andrew Delong, Daria Terekhov

Given a set of observations generated by an optimization process, the goal of inverse optimization is to determine likely parameters of that process. We cast inverse optimization as a form of deep learning. Our method, called deep inverse optimization, is to unroll an iterative optimization process and then use backpropagation to learn parameters that generate the observations. We demonstrate that by backpropagating through the interior point algorithm we can learn the coefficients determining the cost vector and the constraints, independently or jointly, for both non-parametric and parametric linear programs, starting from one or multiple observations. With this approach, inverse optimization can leverage concepts and algorithms from deep learning.

■ TB-14

Tuesday, 10:30-12:00 - H2.20

Routing and Allocation with Integer Programming

Stream: Mixed Integer Programming
Invited session
Chair: Pascal Wortel

1 - Mathematical Formulations for the Periodic Capacitated Arc Routing Problem with Time Windows

Gustavo Loch, Diego Thomaz

In this paper we present the undirected case of the Periodic Capacitated Arc Routing Problem with Time Windows (PCARPTW), based on the application of the problem waste collection planning. Furthermore, two mathematical formulations, transforming the arc routing problem into a node routing problem. The two mathematical formulations were validated on a set of 225 instances of the literature for the Rural Postman Problem with Time Windows (RPPTW), considering up to 60 nodes, 90 edges and 45 required edges. Moreover, 105 of the 225 instances of the RPPTW were adapted for the PCARPTW. Computational results show that the mathematical formulations, proposed here, are competitive with the mathematical formulation for the RPPTW proposed by Monroy-Licht, Amaya and Langevin (2014). Moreover, the results show that the mathematical formulation with valid inequalities is superior to the mathematical formulation without them. The most notable results were obtained on the most complex instances, in which the run time used by the GUROBI solver to obtain an optimal solution reduced on average 73.34% when compared the results obtained about the mathematical formulation with valid inequalities with that one obtained about the mathematical formulation without them. In general, the results presented considering the mathematical formulation with valid inequalities were superior or equal to those obtained with the mathematical formulation without valid inequalities in 84.76% of the instances.

2 - International Roaming Traffic Optimization with Call Quality

Ahmet Şahin, Erinc Albey

In this study we focus on international roaming problem that concerns a telecommunications operator's agreements with other carriers in order to enable subscribers access services, without interruption, when they are out of operators' coverage area. In these agreements, a subscriber's call from abroad is directed to partner operator. The decision for which each call will be forwarded to the partner is based on the user's location (country/city), price of the partner operator for that location and the service quality of partner operator. We develop a mixed integer programming model that considers agreement constraints and quality requirements while satisfying subscribers demand over a predetermined time interval. We test the performance of the proposed approach using different execution policies such as running the model once and fixing the roaming decisions over the planning interval or dynamically updating the decisions using a rolling horizon approach. We present a rigorous tradeoff analysis that aims to help the decision maker in assessing the relative importance of cost, quality and ease of implementation, which is also quite important for the operational feasibility of the proposed approach.

3 - Optimal resource allocation in the flower industry using integer programming

Andrés Miniguano, Diego Recalde, Luis Torres, Juan Pablo Dueñas

Allocation of rose stems in final products is a key issue for production and trading in the flower industry. Several farms with limited capacity grow roses of different stem sizes, colors, and varieties. In order to satisfy customer's requests, different combinations of stems are packed into boxes of bunches or bouquets, according to specific rules. Due to the large number of rose varieties and the flexibility of assembling rules, there is a huge number of possible combinations, called patterns, to get each final product. Moreover, roses can be purchased from third-party farms in order to fulfill large orders during high demand seasons.

The problem consists in maximizing the company's total revenue by optimally allocating rose stems into final products to satisfy customer demands, determining the volume of purchases from suppliers, controlling unsatisfied requests, and decreasing stem waste. An integer programming model for flower allocation is presented along with computational results on real-world instances of a rose producer and distributor.

4 - Speeding up optimal buffer allocation in flow lines
Pascal Wortel, Sven Krumke

In flow line manufacturing industry, buffering is a commonly employed technique to increase production rates. It allows the production process to keep running while one or several machines are blocked, or starved. On the other hand, the use of large buffers is costly. The computation of smallest possible set of buffers that guarantees a given flow rate over the line is referred to as the Buffer Allocation Problem (BAP). The BAP can be solved by integer programming techniques. However, although the approaches presented in literature make use of advanced techniques, they remain tractable only for comparatively small instances. This is even more pronounced when uncertainties are incorporated into the models using concepts of robust optimization. This raises the need for strong lower bounds on the amounts of buffers. Recently, a procedure was described to generate lower bounds by iteratively solving subsystems of the original line, in the particular case that no warm-up is carried out. However, the use of a warm-up phase prior to the actual production process, which is common for the BAP, poses some additional challenges. We propose a method that extends the subsystem bounds to the general case. Furthermore, by setting an alternative definition for the flow line throughput, we derive new bounds that remain unaffected by the warm-up phase, and hence further speed up the computation process. The efficiency of these new approaches is supported by numerical results.

■ TB-15

Tuesday, 10:30-12:00 - H2.32

Descent methods for multiobjective optimization

Stream: Multiobjective Continuous Optimization
Invited session
Chair: Ellen Hidemi Fukuda

1 - Barrier and penalty methods for constrained continuous multiobjective optimization
Fernanda Raupp, Ellen Hidemi Fukuda, Luis M. Graña Drummond

Here, we present a barrier method (MBM) and an external penalty method (MPM)for solving constrained multicriteria problems, with continuous objective and constraint functions. Each method extends the correspondent classical scalar-valued method. Differently from the scalar-valued procedures, both methods are implemented by means of auxiliary "monotonic" real-valued mappings, which may be chosen in a quite large set of functions. Under mild assumptions, and depending on the monotonicity type of the auxiliary function, we show convergence to Pareto or weak Pareto optima. Finally, we also show implementable versions of the methods.

2 - Nonlinear conjugate gradient methods for multiobjective optimization
Leandro Prudente, Luis Roman Lucambio Perez, Max Leandro Nobre Gonçalves

In this talk, we discuss extensions of nonlinear conjugate gradient methods for multiobjective optimizations problems. Our analysis covers the extensions of the Fletcher-Reeves, Conjugate Descent, Dai-Yuan, Polak-Ribière-Polyak, Hestenes-Stiefel and Hager-Zhang methods that retrieve the classical ones in the scalar minimization case. Under inexact line searches and without regular restarts or convexity assumptions, we prove that the sequences generated by the proposed methods find points that satisfy the first-order necessary condition for Pareto-optimality. Numerical experiments illustrating the practical behavior of the methods are presented.

3 - Merit functions for nonlinear multiobjective optimization and convergence rates analysis of proximal gradient methods
Hiroki Tanabe, Ellen Hidemi Fukuda, Nobuo Yamashita

During the last six decades, many algorithms have been developed to solve multiobjective optimization problems. However, the research related to the existence or the boundedness of Pareto optimal solutions is still insufficient. Furthermore, few studies have focused on the computational complexity of algorithms. In this study, we first propose new merit functions for nonlinear multiobjective optimization. These functions return zero at the solutions of the original problem and strictly positive values otherwise. The proposed merit functions extend the one defined in linear multiobjective optimization. Moreover, by investigating the properties of these functions, we show sufficient conditions for the existence of Pareto stationary solutions, and for the boundedness of Pareto optimal sets. Finally, by using these functions, we analyze the convergence rates of the recently proposed multiobjective proximal gradient methods.

4 - On using nonmonotone line searches in multiobjective descent methods
Ellen Hidemi Fukuda, Kanako Mita, Nobuo Yamashita

During the last two decades, many descent methods for multiobjective optimization had been proposed, including the steepest descent and the Newton methods for the unconstrained case, and the projected gradient method for the constrained case. In these methods, at each iteration, a convex subproblem has to be solved to generate the descent direction, and the stepsize is chosen using the Armijo-type condition. In this case, all the objective functions values necessarily decrease in each iteration. In this work, we are interested in nonmonotone line searches, i.e., we consider the case that some increase in the objective functions values are allowed. We study two types of nonmonotone approaches: the one that takes the maximum of all previous functions values, and the one that takes their average. Based on these techniques, we also propose a hybrid-type nonmonotone line search. The global convergence is obtained for all these nonmonotone approaches, and with a general search direction. Finally, we show from the numerical experiments that the descent methods are more efficient using the hybrid-type nonmonotone technique.

■ TB-16

Tuesday, 10:30-12:00 - Theatre A

Mixed Integer Non Linear Optimization: Methods and Applications

Stream: Combinatorial Optimization II
Invited session
Chair: Claudia D'Ambrosio

1 - Gaining or losing perspective
Jon Lee, Emily Speakman

We study mixed-integer nonlinear-optimization formulations of the disjunction x in [l,u], where z is a binary indicator of x in [l,u], and y "captures" xp, for p>1. This model is useful when activities have operating ranges, we pay a fixed cost for carrying out each activity, and costs on the levels of activities are strictly convex. One well-known concrete application (with p=2) is mean-variance optimization (in the style of Markowitz).

Using volume as a measure to compare convex bodies, we investigate a family of relaxations for this model, employing the inequality yzq

>= xp, parameterized by the "lifting exponent" q in [0,p-1]. These models are higher-dimensional-power-cone representable, and hence tractable. We analytically determine the behavior of these relaxations as functions of l,u,p and q, enabling use in modeling and algorithmic decisions. We validate our results computationally, for the case of p=2. Furthermore, for p=2, we give results on optimal branching-point selection (in the context of spatial branch-and-bound).

This is joint work with D. Skipper (USNA) and E. Speakman (Magdeburg).

2 - Stability in quadratic convex reformulation of unconstrained binary polynomial optimization

Arnaud Lazare, Sourour Elloumi, Amélie Lambert

We address the problem of stability in quadratic convex reformulation of polynomial programs. We present the main ideas behind PQCR, our three-phases algorithm to solve unconstrained binary polynomial programs. The first phase consists in a quadratic reformulation (quadratization) of the polynomial program (P) to obtain an equivalent non-convex quadratic program (QP). Then in the second phase, we compute a tight convex reformulation of (QP) using semidefinite programming. This convex reformulation uses valid equalities coming from the first phase. We then solve the obtained quadratic convex program by a branch and bound algorithm. We observe that the bound at the root node is dependent on the quadratic reformulation performed in the first phase and can thus vary between two quadratizations. In this paper, we highlight some properties for stabilizing families of quadratisation, i.e. that lead to the same bound after convexification.

3 - A computational comparison of quadratizations for polynomial binary optimization problems

Elisabeth Rodriguez-Heck, Endre Boros, Yves Crama

The problem of minimizing a polynomial in binary variables finds many applications in operations research and management science but also in more distant fields like computer vision or quantum computing. A quadratization is a reformulation of this nonlinear problem into a quadratic one, obtained by introducing a set of auxiliary binary variables. A desirable property for a quadratization is to introduce a small number of auxiliary variables. We present logarithmic upper and lower bounds on the number of auxiliary variables required to define a quadratization for positive monomials which improve previous bounds by orders of magnitude. Understanding quadratizations of monomials is particularly interesting because one can define a quadratization of a polynomial by reformulating its monomials separately. However, there are other methods to define quadratizations in which different monomials use common auxiliary variables. These quadratizations do not necessarily introduce less auxiliary variables but sometimes present other interesting properties, like having a small number of positive quadratic terms which can be interpreted as an empirical measure of distance from submodularity. We present the results of an extensive set of experiments comparing the computational performance of different quadratization methods with the aim of providing an indication of which quadratizations are most suitable in practice.

4 - Decomposition Methods for Distributed Control of Microgrid Networks

Dimitri Thomopulos, Li Bai, Emanuele Crisostomi, Gabriele Pannocchia

A microgrid (MG) consists of a collection of power generation sources, loads, and storage devices. It can either work in island mode, or in a grid-connected mode. MGs are becoming a fundamental unit of a power system. It is expected that in the near future several MGs will be established to optimize power generation and consumption in small areas (e.g., neighbourhoods, universities, companies). While such MGs will primarily focus on delivering the required energy with the minimum cost, still they will compete in the market to sell possible exceeding power generation to maximize their revenues. Most likely, they will do this without being willing to share their relevant data (e.g., power generation and consumption) as required in a centralized formulation of the problem.

We propose a distributed formulation, and some decomposition approaches in order to obtain a single subproblem for every MG. Therefore, each MG solves the corresponding subproblem and shares only part of its data, satisfying its privacy requirements. We compare different decomposition approaches for solving the distributed formulation, based on lagrangian decomposition and alternating direction method of multipliers.

■ TB-17

Tuesday, 10:30-12:00 - A005

Real Options in the Energy Sector

Stream: Technical and Financial Aspects of Energy Problems

Invited session

Chair: Lars Sendstad

Chair: *Verena Hagspiel*

1 - Green Capacity Investment under Subsidy Withdrawal Uncertainty

Roel L.G. Nagy, Verena Hagspiel, Peter M. Kort

We study the effect of a potential subsidy retraction of a lump-sum subsidy on optimal investment timing and size. We find that increasing the probability of subsidy withdrawal increases the incentive to invest earlier but decreases the optimal investment size. We show that a firm investing at the optimal timing installs larger capacity when the policy is not provided than when it is. Providing a larger subsidy the policy maker is able to accelerate investment but only at the cost of smaller investment. If a policy maker aims at maximizing welfare, we show that the larger the policy uncertainty the smaller the subsidy that should be provided.

2 - Sequential Investment in Emerging Technologies under Policy Uncertainty

Lars Sendstad, Michail Chronopoulos

Although innovation and support schemes are the main forces that drive investment in emerging technologies, such as renewable energy, both involve considerable uncertainty. Therefore, we develop a real options framework to identify the implications of each source of uncertainty as well as their combined impact on the decision to invest sequentially in successively improved versions of an emerging technology. Technological uncertainty is reflected in the random arrival of innovations and policy uncertainty in the likely provision or retraction of a subsidy that takes the form of a fixed premium on top of the output price. We show that greater likelihood of subsidy retraction lowers the incentive to invest, whereas greater likelihood of subsidy provision facilitates investment. However, embedded options to invest in improved technology versions raise the value of the investment opportunity, thereby mitigating the impact of subsidy retraction and making the impact of subsidy provision more pronounced. Additionally, by allowing for sequential policy interventions, we find that the impact of policy uncertainty becomes less pronounced as the number of policy interventions increases.

3 - Investments in domestic PV plants paired with energy storage: a stochastic dynamic optimization model

Chiara D'Alpaos, Francesca Andreolli, Michele Moretto

Renewable energy technologies are expected to play a major role in mitigating climate change and resource depletion and contributing to domestic energy security. Due to the intermittent nature of solar photovoltaic (PV), there are often significant gaps between electricity consumption and electricity supply by PV plants. This makes storage systems a potential option to maximize savings and accrue managerial flexibility by increasing the quota of self-consumed electricity, while guaranteeing adequate power levels in distribution grids. This paper provides a theoretical framework modelling prosumers' decision to invest in domestic PV plants paired with batteries. To capture the value of managerial flexibility related to the decision to install both a PV plant and a battery, we implement a real option approach and propose a stochastic optimization model, which we calibrate and test with data from the Italian energy market. Our findings show that the option of storing energy via batteries increases investment values: the connection to batteries increases managerial flexibility, as prosumers can optimally exercise the option to decide the prosumption quota and switch from prosumption to production. The opportunity to sell energy in the market and store it via batteries encourages prosumers to invest in larger plants compared to those needed for self-consumption: there is a positive relation between optimal size and optimal investment timing of both batteries and PV plants.

■ TB-18

Tuesday, 10:30-12:00 - C112

OR in Quality Management

Stream: OR in Quality Management
Invited session
Chair: Bora Cekyay

1 - Concurrent design of product quality and supply chain using HOQ
Shuki Dror

Quality Function Deployment (QFD) has been originally developed as a product quality design methodology. The House of Quality (HOQ), the first matrix in the QFD, maps the WHATs representing desired customer product attributes (the customer's voice) into the HOWs - that is, technical measurable characteristics as viewed by the development team. In this work an enhanced HOQ is developed for integrating product quality design with supply chain design. Unlike the classical HOQ recommended in the QFD, in the construction of the enhanced HOQ, it is assumed that synergy between the product/service characteristics might be changed for each customer/supply chain requirement. A case study for building an enhanced HOQ in a food processing company is presented. The enhanced HOQ was carried out by multidisciplinary representatives from the entire company. The team pointed out that for the customer requirement "Fresh", there is positive synergy between "Life length" and "Delivery time", i.e., the product life length will be more valuable, when the delivery time is short. When the delivery time is too long, the product's quality characteristics of the food product might be hurt. In contrast, our team confidently posited absence of synergy between "Life length" and "Delivery time" for the retailers' requirement "Cost of Stock".

2 - A Method for Monitoring and Evaluating Quality in Long Run Product Development Projects
Gülçin Özden, Gülser Köksal

For complex products, product development takes long time and late delivery and customer dissatisfaction may be inevitable if product quality is not assured from the beginning of the development. The aim of this study is to propose a method to monitor and evaluate such product development projects from the viewpoint of product quality as well as time. The method proposed is built mainly upon Quality Function Deployment (QFD). QFD is already a frequently used approach in relating customer needs to product and process parameters and prioritizing critical success factors of the development. With the extension that we propose, QFD is used also in predicting customer satisfaction rates by collecting realization information throughout the product development. At each phase, project managers are able to see the engineering requirements fulfillment and customer satisfaction metrics, and compare them to planned ones, so that they can prioritize the tasks accordingly. This method is expected to be useful especially in defense industry projects, in which customers order specialized products with explicit requirements and development phase takes several years.

3 - Reliability of Mission-Based k-out-of-n Systems with Exponential Phase Durations and Component Lifetimes
Bora Cekyay

This study focuses on the reliability analysis of k-out-of-n systems which are designed to perform a given mission consisting of several distinct phases. As the phases of the mission change, the reliability characteristics of the system and the system structure vary accordingly. The phase transition probabilities, phase durations, and component failure rates are dependent on the number of operating components. Moreover, the system is allowed to have cold, warm, or hot standby components. Assuming that the phase durations and component lifetimes are exponentially distributed, we propose computationally tractable methods to compute the system reliability, mean time to failure, and long-run availability for such a system structure. We also provide a numerical example to show the applicability of the proposed methods.

■ TB-19

Tuesday, 10:30-12:00 - C115

Emerging Collaborative Economics and Management under Uncertainty 2

Stream: Emerging Collaborative Economics and Management under Uncertainty
Invited session
Chair: Gerhard-Wilhelm Weber
Chair: Alexander Vasin

1 - On the price of anarchy in a single-server queue with heterogeneous service valuations.
Irit Nowik, Refael Hassin, Yair Shaki

This work presents a strategic observable model where customer heterogeneity is induced by the customers' locations and travel costs. The arrival of customers with distances less than x is assumed to be Poisson with rate equal to the integral from 0 to x, of some nonnegative intensity function h. In a loss system M/G/1/1 we define the threshold Nash equilibrium strategy xe and the socially-optimal threshold strategy x*. We investigate the dependence of the price of anarchy (PoA) on xe and h. We find that if the potential arrival rate is bounded then PoA is bounded and converges to 1 when xe goes to infinity. On the other hand, if the potential arrival rate is unbounded, we prove that x*/xe always goes to 0, and yet, in some cases PoA is bounded and even converges to 1; We find that the number 2 plays a central role in our model: if h converges to a positive constant then PoA converges to 2; if h increases (decreases) then the limit of PoA is at least (at most) 2; If the integral of h is infinite then the limit of PoA equals 2+the derivative of h divided by h. In a system with a queue we prove that PoA may be unbounded already in the simplest case of uniform arrival.

2 - The Inmate Transportation Problem and its Application in the PA Department of Corrections
Tamás Terlaky, Mohammad Shahabsafa

The Inmate Transportation Problem (ITP) is a common complex problem in any correctional system. We develop a weighted multi-objective mixed integer linear optimization (MILO) model for the ITP. The MILO model optimizes the transportation of the inmates within a correctional system, while considering all legal restrictions and best business practices. We test the performance of the MILO model with real datasets from the Pennsylvania Department of Corrections (PADoC) and demonstrate that the inmate transportation process at the PADoC can significantly be improved by using operations research methodologies.

3 - Pharmaceutical Supply Chains: Stakeholders and Data Management Plans
Joao Miranda, Sarah Ben Amor

The engagement of stakeholders in pharmaceutical supply chains (SC) and the related data management plans are very important to foster international cooperation and mitigate the disruptions originating drugs shortages. For that, the typical initiative to promote the engagement of SC stakeholders considers also a comprehensive data agreement, including the data management issues within each stakeholder, and specific addenda on data privacy, intellectual property rights, and patents. The utilization of advanced IBM tools, both for data treatment and modeling-simulation-optimization, is contributing for the governance and control of drugs shortages in a proactive manner, while the impacts on patients and healthcare systems are addressed. In this work, it is presented a multi/trans-disciplinary research including pharmaceutical and health sciences, either regulatory or finance topics, and the main contributions for long-term and international solutions in drugs shortages are discussed too.

4 - PhD in progress: The Impact of Analytics 3.0 on the Product Quality from an R&D perspective: The Case of the Software Product Development
Amine Bejhih, Guangming Cao, Yanqing Duan, Golda Komanapalli

Analytics 3.0 infrastructure plays an important role in sensing signals generated by the environment of competitors in the market of the software product development (SPD). Such signals trigger a succession of changes throughout the SPD process to accommodate the software product with the new requirements, which may, in turn, results in changes in the allocated R&D budget for investment in the analytics 3.0 infrastructure. Such investments can be oriented towards the acquisition and integration of a new infrastructure to improve competitiveness of the company. Research that link product development with analytics 3.0 and big data analytics is scarce. This research aims at understanding the impact of analytics 3.0 on the software product quality, and what influence does such an impact have on the size of investments in analytics 3.0 infrastructure' readiness in R&D departments. The research adopts a system dynamics approach of a holistic view that captures product development and R&D processes, both of which, information is key. In such processes part of the generated knowledge is endogenously created. They are complex, highly dynamic, and heavily rely on causality and feedback structures. It is expected that both poor and high achievements in the product quality may lead to increasing investments in analytics 3.0 infrastructure that aim at increasing or maintaining competitiveness by improving the sensing and information processing capabilities.

■ TB-20

Tuesday, 10:30-12:00 - C006

Business Analytics II

Stream: Business Analytics
Invited session
Chair: *Kristof Coussement*
Chair: *Dries Benoit*

1 - Using Real-time Operational Data To Increase Labor Productivity In Retail
Pablo Jofré, Marcelo Olivares, Andrés Musalem

This research is focused on developing models to support dynamic systems that can reassign labor to different activities. This work utilizes data from a pilot study in a store of a home improvement retail chain in the U.S. Security cameras were used to track the number of customers and employees on different sections. We use these operational data to measure - in real time - the demand for services in a specific store department, and the service capacity. This information can be linked to point of sales data, to measure the effect of the number of employees on the sales of specific departments. All this provide information for a dynamic labor allocation system in order to prioritize where to allocate employees.

2 - Market Basket Analysis for a Food Service Company Using Association Rule Mining
Ege Ceyhan, Erinc Albey, Ahmet Şahin

Market basket analysis helps companies in their campaign management activities such as bundling, pricing, and shelf allocation, which in turn yield to increase net profit margins. Bundling items which are used or sold together creates attractiveness for customers and enable cross selling and upselling with some possible price advantages. Several methods are used to determine rules, that help to determine antecedent and consequent items. In this study, the aim is to create bundles for online and in restaurant menu in order to boost sales. The dataset contains customers' order information that contains approximately 15,000 transactions of a popular steakhouse in Turkey. Apriori algorithm is used for creating association rules. Bundles are created according to the rules determined. Although the classic market basket analysis tries to increase the amount of sales of the associated product, in this study a different use case is proposed, where associated product is offered for a discounted price in order to increase the attractiveness of the antecedent item. As a result, several new bundles are created and added into both online and dine-in menu. The impact of these bundles on the sales and profit margins is currently being monitored by the firm and will be reported.

3 - Measuring the Effectiveness of Direct Response TV Advertising on Sales
Maryam Rezaei, Mee Chi (Meko) So, Christophe Mues, Teck-Yong Eng

Even in today's digital world, TV still plays a pivotal role due to the high number of television viewers and the time which people still spend to watch TV programmes. Direct Response TV(DRTV) is an efficient and powerful method of advertisement to create awareness and drive consumer interest. Retailers are still investing extensive amount of money on DRTV that needs to be justified. A key challenge in advertising response modeling is how to relate the actual sales to a specific ad. In this paper, the actual purchase amount is defined as outcome variable and a zero-adjusted negative binomial generalised linear regression model(ZINB) is used for examining the impact of different advertisement features such as the time of broadcasting, the duration of ad, the day of the week and media type on the ultimate effectiveness of DRTV commercials. Our proposed model presents a powerful alternative approach to ad response modeling. The model is applied to a data set of a DRTV ad agency based in Japan. Unlike previous research, the unique feature of our data set is the actual number of purchase order and order value, instead of only the number of calls by customers. Our findings indicate that although the broadcast time and the duration of DRTV ads are significant factors in terms of increasing sales, longer ads not necessarily generate more sales. Moreover, unlike previous research findings, we achieved the highest ad response in the evening rather than early morning or afternoon.

4 - Research on Comments of Online Merchandise Based on Sentiment Mining in Attribute Level. A Case Study of Entry-level SLR Cameras in Jingdong Mall
Yue He, Chuanpeng Xu, Tingting Zhu, Bochi Cai, Xiaowen Jie, Shuangyi Zheng, Dan Zhang

Sentiment analysis is a key branch of data mining and computer linguistics. With big data has become acurrent and future research frontier, sentiment analysis has attracted significant research attention too. This paper proposed an attribute words mining algorithm based on Naive Bayesian classification method combined with the association rules to research the commented consumers' emotion of entry-level SLR cameras in Jingdong Mall. The comments information was collected by gooseeker, then data preprocessing was carried out; and next tractate analyzed the sentiment of the collected comments with this new method and came to an efficient result. The aims of this study are summarized into three aspects: (1) to verify if the new method can effectively analyze the consumer's emotion; (2) to obtain the most concerned ten attributes of entry-level cameras by consumers and the best and worst propertie attributes of these five products respectively; and (3) to establish a set of factor analysis system based on the product attributes indexes to help consumers and businesses identify the properties of a single product is good or bad through the comments information.

■ TB-21

Tuesday, 10:30-12:00 - F101

Lot Sizing V - Integrated lot-sizing

Stream: Lot Sizing, Lot Scheduling and Production Planning

Invited session

Chair: *Mehdi Charles*

1 - Multi-plant lot sizing problem and cutting stock problem: an integrated approach

Livia Pierini, Kelly Cristina Poldi

In many manufacturing industries, large objects are produced and then cut into smaller units in order to meet a given demand. In the optimization of such productive processes, the Cutting Stock Problem (CSP) and the Lot Sizing problem (LSP) arise. In a specific context, with multiple plants (factories) and limited production capacity, the LSP is characterized as Multi-plant Capacitated Lot Sizing Problem (MPCLSP). In general, the CSP can be considered a fundamental subproblem of the LSP. In the last decades, studies addressing these two problems in a integrated way have become a trend and several models and solution methods proposals have been developed. These studies confirm that better results can be obtained through the integrated models and also that some techniques present better solutions with certain problems, which motivates new approaches with different models and combining different techniques. Against the abstance of studies addressing the integrated MPCLSP and CSP and its potential of application and demand by the industries, in this present research, we proposed a formulation for the integrated MPCLSP and CSP. The proposed model aims to minimize the production, inventory and setup costs, the transfer cost of objects between plants and the material waste in the cutting process, considering a planning horizon with multiperiods and one-dimensional cutting process.

2 - A Hybrid Evolutionary Optimization Algorithm for the Production Routing Problem

Stelios Nikolakakis, Pantelis Lappas, Manolis Kritikos, George Ioannou

The Production Routing Problem (PRP) is concerned with two well-known problems widely studied in academia: the lot-sizing problem (LSP) and the vehicle routing problem (VRP). The PRP optimizes the total system costs related to production, inventory and routing decisions. The PRP is an NP- hard problem due to its combinatorial nature. We consider a PRP formulation that consists of a single plant, single product and homogenous set of capacitated vehicles for delivering products to customers. We propose a hybrid evolutionary optimization algorithm for solving the PRP. The main idea is to decompose the problem into two main parts the LSP and VRP and to use an iterative two phase scheme to solve the PRP. Preliminary results on benchmark datasets are promising.

3 - More realistic test instances for the Capacitated Lot-Sizing Problem

Mehdi Charles, Stéphane Dauzere-Peres, Safia Kedad-Sidhoum

Multi-item capacitated lot-sizing problems are frequently found in the industry. Oftentimes, in addition to a fixed setup cost, producing an item in a period induces a fixed setup time to set the production system in the right configuration, which deeply affects the complexity of the problem.

The most well-known instances for this type of problems are the ones proposed by Trigeiro et al. in 1989. These instances have multiple items and each time period has a limited production capacity, which is affected by both the fixed setup and variable processing times for each product.

We first analyze limitations of these instances from a practical point of view, in particular the fact that there are no initial inventories. We show that this is not compensated by the fact that some demands in the first periods are randomly set to zero. More precisely, many setups occur in the first time periods although this would rarely be the case in practical situations.

Following our analysis, we modify the instances of Trigeiro et al. by considering initial inventories for items and imposing an ending inventory for all items. We also discuss computational experiments on these new instances that will be made available to researchers in the lot-sizing field.

■ TB-22

Tuesday, 10:30-12:00 - F102

Production Planning and Control for Semiconductor Manufacturing II

Stream: Production Planning and Control for Complex Manufacturing Systems

Invited session

Chair: *Chirine Millauer*

1 - Production Planning with Flexible Lead Times in Semiconductor Manufacturing

Sébastien Beraudy, Nabil Absi, Stéphane Dauzere-Peres

Semiconductor manufacturing facilities (fabs) probably include the most complex manufacturing processes, with hundreds of products, each requiring hundreds of operations on hundreds heterogeneous machines. Moreover, a product is processed in the same workshops dozens of times in its route. This leads to significant congestion in the fab and to cycle times of several months. In the current literature on production planning in semiconductor manufacturing, the congestion is mainly modeled using fixed lead times, iterative simulation-optimization methods or clearing functions. Because the last two types of approaches can be difficult to use in practice, the use of fixed lead times remains popular although they are often too constraining. In this work, we investigate the use of flexible lead times through WIP penetration constraints in a production planning model as an alternative to the classical fixed lead time constraints. Indeed, WIP penetration constraints allow for more flexibility, thus helping to better use production capacity and reduce cycle times. Our models are first validated on small instances, and then tested on large industrial instances.

2 - Semiconductor Supply Chain Planning Under Uncertainty

Eghbal Rashidi, Scott Mason

We study a multi-product semiconductor supply chain risk management under uncertainties due to production and process yields, and market demand. We consider the possibility of outsourcing for each production and processing stages of the supply chain (e.g., fabrication, sort, assembly, and test). The problem is modeled as a three-stage stochastic programming with recourse. Our computational results show that our proposed stochastic programming model produces solutions that are significantly better than the solutions provided by the deterministic-equivalent expected value approach.

3 - A Multi-Period Machine Qualification Management Problem for Semiconductor Manufacturing
Antoine Perraudat, Stéphane Dauzere-Peres, Philippe Vialletelle

In semiconductor manufacturing, before executing a given operation of a product, a machine must be qualified, i.e., certified, to ensure quality requirements. The qualifications of machines in a workcenter are essential to the overall performance of the manufacturing facility. However, performing a qualification is expensive and takes time, although the more qualified the machines, the more flexible the production system. Qualification management aims at determining the right qualifications at the lowest cost. We first discuss the limitations of a single period modelling approach, in particular due to capacity losses and delays inherent to qualification procedures. Then, we explore and motivate a multi-period modelling approach. Finally, we compare both approaches in a computational study on industrial instances.

4 - Mathematical modelling of product allocation to customers for semiconductor industry
Chirine Millauer, Radhia Azzouz, Behrouz AlizadehMousavi, Cathal Heavey, Randolph Knobloch

In tight supply situations, it is challenging for suppliers to ensure that the available supply matches customers' dynamic demand. Consequently, demand fulfilment and the ability to respond quickly to customer orders have become key factors in gaining competitiveness in the semiconductor industry. It appears that in tight supply situations, customers tend to exaggerate their demand forecasts with the intention to secure their product supply. Recent advanced planning systems (APS) provide computer-based optimization for the allocation of available supplies of finished products to fulfil customers' orders. However, in supply shortage situations, APS are not sufficient and further human intervention is needed. The current manual interference is based on experience without applying any rules or heuristic algorithms. This paper presents a mathematical model for the optimization of available-to-promise (ATP) allocation to customers. Allocation managers could use this mathematical model as a decision support tool to analyse all possible allocation scenarios. The objective of the model is to maximize customer satisfaction by reducing the number of potential escalations. The result of this study will support allocation managers to efficiently allocate current and future supply to customers and to evaluate the executed allocation.

■ TB-23

Tuesday, 10:30-12:00 - F103

Perishable Inventories and Food Waste

Stream: Demand and Supply Management in Retail and Consumer Goods
Invited session
Chair: Pedro Amorim

1 - The value of expiration date visibility when controlling perishable inventories
Rob Broekmeulen, Karel van Donselaar

Modern technology enables retailers to increase the visibility of expiration dates for perishable items. Using this information when controlling the inventories for these items enables retailers to increase their performance. This paper compares multiple scenarios having different levels of expiration date visibility. The type of technology and the procedures needed in the stores vary in each of these scenarios. For a wide range of perishable items, the total costs for out-of-stocks, waste and holding inventory are compared for these scenario's, using simulation. As expected, the scenario with full visibility of expiration dates offers the lowest costs. One way to achieve this full visibility is via an investment with RFID tags on each consumer unit. However, a large part of the benefits from full visibility can be gained by a scenario with partial visibility requiring a smaller investment. In the latter scenario, only at the moment a new batch arrives in the store, the expiration date and the quantity of that batch is registered, e.g. by reading an extended barcode from each case pack. A sensitivity analysis is performed to find out how the performance of the partial visibility scenario depends on the accuracy of the estimated grabbing behavior of consumers.

2 - Comparing preferences for e-grocery logistics services between urban and rural customers
Martin Waitz, Christian Fikar

The complexity of logistics operations for the last-mile delivery of fresh food (e.g., fresh fruits) is considerably larger compared to other products (e.g., books or electronics). Reasons for that are the perishability of the products and the greater involvement of the customer at the moment of delivery. This work investigates the needs and preferences of customers for logistics services (e.g. remaining shelf-lives, delivery fees or time between order and delivery) of an e-grocer, focusing on the differences between urban and rural customers. Therefore, two surveys have been conducted, one for the rural area (n=428) and one for the urban area (n=432) of Austria, including a choice-based conjoint analysis allowing the estimation of individual part-worth utilities for the different logistics services. Based on these results, a simulation and optimization-based decision support system is developed, where an agent-based simulation generates demand and a dynamic vehicle routing procedure plans delivery routes considering remaining shelf-lives of products by modelling transportation durations and temperatures. Differences regarding the e-grocery shopping behaviour between rural and urban customers are identified such as varying preferred delivery times. Heterogeneity among the preferences within both groups exists and results from the decision support system show that an e-grocer benefits greatly from incorporating this heterogeneity in daily operations.

3 - Waste considerations in Food Supply Chain
Sara Rezaee Vessal, Sam Aflaki

In the food supply chain, we face a huge volume of waste of fresh food, while one of the worldwide concern is to overcome hunger. During the last couple of years, there are different movements toward collecting food from supermarkets, producers, and restaurants and distributing them among people who need them, to both decreases the waste of fresh food and also because of environmental concerns. Nowadays, there is no stylized mechanism for the suppliers (e.g. supermarkets) to distribute food among the distributors. In this paper, we study the capacity allocation of a scarce and perishable product among stockout-averse retailers that face stochastic demand. We focus on two commonly practiced allocation mechanisms and using a dynamic model characterize the conditions under which each allocation mechanism performs superior from a waste point of view.

4 - Coordinated discrete pricing and inventory control for perishables under price dependent stochastic demand
Yann Bouchery, Asma Jbira, Amel Jaoua, Zied Jemai

Perishables such as fruits, vegetables, dairy products and meat often account for a large share of sales at grocery stores. Those products require an effective management due to their limited lifetime. The most common causes for disposing perishables by retailers are overstocking and inaccurate demand forecasting. In this regard, the selling price plays a crucial role on determining demand, since most consumers have predetermined standards of price versus quality. In this study, we show that a discrete pricing policy coupled with an appropriate inventory management and disposal policy often enables improving profit while reducing waste.

To this end, we begin with developing a mathematical model to optimize the problem in a deterministic setting. Then, in order to model the real stochastic behavior of demand while dealing with the complexity of the problem, we develop a simulation-based optimization method and we investigate the capability of our method to solve the stochastic problem. Through a numerical study, we observe that discrete pricing outperforms fixed pricing policy in terms of profit and waste. The difference in profit is about 20% on average and the wasted quantity decreases by 56% on average on the instances tested.

■ TB-24

Tuesday, 10:30-12:00 - F103A

Inventory Management in Supply Chains

Stream: Supply Chain Management
Invited session
Chair: Danja R. Sonntag

1 - Energy-saving queueing policies for production systems with a heater
Gerlach Van der Heide, Michiel uit het Broek, Nicky Van Foreest

Numerous practical examples exist of production systems with servers that require heating in order to process jobs. Such production systems may realize considerable energy savings by temporarily switching off the heater and building up a queue of jobs to be processed later, at the expense of extra queueing costs. We optimize this trade-off between energy and queueing costs by modeling the production system as an M/G/1 queue with a temperature controlled server that can only process jobs if a minimum production temperature is satisfied. The time and energy required to heat a server depend on its current temperature, hence the setup times and setup costs for starting production are state dependent. We derive the optimal policy structure for a fluid queue approximation, called a wait-heat-clear policy. Building upon these insights, for the M/G/1 queue we derive exact and approximate costs for various intuitive types of wait-heat-clear policies. Numerical results indicate that the optimal wait-heat-clear policy yields average cost savings of over 40% compared to always keeping the server at the minimum production temperature. Furthermore, an encouraging result for practice is that simple heuristics, depending on the queue length only, have near-optimal performance.

2 - Controlling Distribution Inventory Systems with Shipment Consolidation and Compound Poisson Demand
Danja R. Sonntag, Lina Johansson, Johan Marklund, Gudrun Kiesmuller

We consider a one-warehouse-multiple-retailer inventory system where the retailers face stochastic customer demand, modelled as compound Poisson processes. Deliveries from the central warehouse to groups of retailers are consolidated using a time based shipment consolidation policy. This means that replenishment orders have to wait until a vehicle departures, which increases the lead time for the retailers and therefore also the safety stock. Thus, a trade-off exists between shipment cost and holding cost. Our aim is to determine the shipment intervals and the required amount of safety stock for each retailer and the warehouse to minimize total cost, both for backorder costs and fill-rate constraints. Previous work has focused on exact solutions which are computationally demanding and not applicable for larger real world problems. The focus of our present work is on the development of computationally attractive heuristics that can be applied in practice. A numerical study illustrates that the proposed heuristics perform well compared to the exact cost minimizing solutions. We also show that the approaches are appropriate for solving real world problems using data from a large European company.

3 - Heterogeneity and asymmetry in ordering quantities of non-standard newsvendor models
Lena Silbermayr, Werner Jammernegg, Peter Kischka

We discuss heterogeneity and asymmetry in ordering behavior of three non-standard newsvendor models that include behavioral factors to explain empirical ordering quantities from newsvendor experiments: the reference-dependent newsvendor model with psychological costs of overordering and underordering, the extended mean anchor newsvendor model and the generalized overconfident newsvendor model. We show that these intuitive non-standard newsvendor models can exhibit the Pull to Center effect at the aggregated level and, in addition, allow heterogeneity and asymmetry in ordering behavior. We analytically exploit the relationships of the respective behavioral parameters and prove, e.g. that if a reference dependent newsvendor whose psychological costs of overordering are higher than that of underordering then this attitude is equivalent to that of a generalized overconfident newsvendor who beliefs that demand variability of the high-profit product is less than that of a low-profit product. The behavioral parameters of the extended mean anchor newsvendor model and the generalized overconfident newsvendor model can be interpreted as indicators of asymmetric ordering behavior. We illustrate the relevance of our results by a laboratory experiment in order to support our theoretical findings with empirical data.

4 - A simulation approach for the tactical two-echelon inventory routing problem
Katyanne Farias de Araújo, Dominique Feillet, Khaled Hadj-Hamou, Claude Yugma

New management policies have emerged aiming at limiting the traffic of large vehicles and their speed in city centers. In order to coordinate freight flows from a far supplier to customers located in city areas, Distribution Centers (DCs) are introduced. The use of DCs has proven to be efficient to reduce the emission of polluting gases and noise levels. Therefore, we introduce the Tactical Two-Echelon Inventory Routing Problem (T-2E-IRP) based on an industrial problem faced by a gas distribution company. The T-2E-IRP consists of deciding which DC will supply each customer and using which vehicles. These decisions are made based on operational costs for a two-echelon delivery system on a long-term and with uncertain demands. We develop a simulation method to solve the T-2E-IRP on a long-term. The assignment of customers and vehicles to the DCs are made based on a short time horizon by a proposed formulation. Then, we evaluate these assignment decisions through a simulation tool that solves the operational problem, i.e., the decisions of deliveries from the supplier to the DCs and from the DCs to the customers, on a rolling-horizon framework. In other words, the operational problem is solved for p-periods. Then, the decisions made in the first r-periods are fixed and the process iterates until the whole horizon has been considered. Computational experiments are performed for a set of randomly generated instances. The impact of several parameters on the total cost is analyzed.

■ TB-25

Tuesday, 10:30-12:00 - F104

Inventory Management

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: Emre Berk

1 - Optimizing the speed of screening in an EPQ model with nonlinear defect detection rate
Zsuzsanna Hauck, Boualem Rabta, Gerald Reiner

A manufacturing process with two stages of quality control is being considered. The screening during the initial production process is of high priority at the company since the proportion of defections before this stage is rather high, and the following production steps are expensive. Based on these facts, all the items are checked at both stages. Due to the complexity of the product, the speed of the screening during initial production might be adjusted and the defect detection rate depends on the speed of the screening in a nonlinear way. Even though, the speed-dependent screening cost function is linear. Final screening is assumed to be perfectly reliable, and its speed is given by standard. Processing and screening costs are assumed to arise at both stages in addition to the setup and inventory costs. A mathematical model is developed and analyzed to find the optimal production parameters jointly with the optimal speed of screening during production, i.e. the optimal capacities at the first stage of quality control. Sensitivity analysis as well as numerical examples are added for better illustration.

2 - Compound Poisson demand forecasting for inventory control

Dennis Prak, Ruud Teunter, Mohamed Zied Babai, John Boylan, Aris Syntetos

Most companies store demand data periodically (e.g. weekly) and make periodic demand forecasts, although inventories are controlled continuously. The same 'mismatch' can be observed in the literature; most forecasting methods are periodic, but inventory control theory often assumes the demand process to be continuous and given. Guidance on estimating the parameters of a continuous demand process from period demand data is lacking, in particular for the popular and well-studied compound Poisson class of demand. Commercial software packages wrongly fit compound Poisson processes based on period Size-Interval forecasting methods, leading to dramatic overshoots of the target service level and therefore too high inventory costs. Standard statistical methods have severe biases in finite samples (method-of-moments - MM) and/or are not available in closed form (maximum likelihood - ML). We propose an intuitive, consistent, closed-form MM alternative that dominates in terms of estimation accuracy and on-target inventory performance.

3 - Optimization of two-level supply chain with human factors and variable lead time using Taguchi Methods

Matloub Hussain, Mehmood Khan

The classical Economic Order Quantity (EOQ) model endeavors to achieve optimization in the field of inventory management across supply chains. Most of the literature on supply chains, with EOQ model, ignores the role of quality, human factors and variability in lead-time-demand, while trying to improve its performance. This paper attempts to fulfill this gap in literature and investigates the combined effect of learning, defective items, inspection errors and stochastic lead time demand on the optimal cost of a two level (vendor-buyer) supply chain. A simple solution procedure along with Taguchi's design of experiments is proposed to compute the impact of the different parameters on the cost of supply chain, the interactions that occur between these parameters and the optimal solution to this model. Finally, a discussion on management insights is presented to complement the model and results.

4 - Newsvendor Problem Revisited with Multiple Deliverables

Emre Berk

Many products come in 'bundles' of a tangible product and services to be provided during its lifetime such as warranties, repairs and upgrades. Although there is a vast literature on determining optimal quantities of products in the face of initial demand uncertainty, there appears a gap in the literature on the impact of multiple deliverables on such decisions.

In this talk, I present an overview of a stream of research which considers such a setting in a stylized newsvendor framework. I develop a number of models that successively capture the intricacies arising from uncertainty of deliverables, financing constraints and, finally, taxation.

For the specific models, the fundamental decisions and trade-offs and optimality results will be presented. Illustrative numerical examples are also provided for sensitivity analyses.

■ TB-26

Tuesday, 10:30-12:00 - F106

International Aspects of OR II

Stream: International Aspects of OR
Invited session
Chair: Ulrike Reisach
Chair: *Gerhard-Wilhelm Weber*

1 - Application of Operation Research for Improving Business Performance with reference to small and medium enterprise in Vidharbha Region, Central India

Rashmi Shahu

Decision-making is crucial process of any business for gaining sustainable profit. There are several steps to pass through before arising on optimal decision for enhancing business performance. The Industrial Scenario of Vidharbha Region in India consists of small and medium manufacturing units. The performance indicators for these industries focus on Economical factors like costs, revenue and profit sharing. The economical sustainability is the main target for these industries in decision making process ignoring the Environmental and Social performance indicators. The Indian government policies play important role in any economical decision making for these industries. Traditional Operations Research Techniques like Forcasting, Planning, Scheduling, Facility Planning, Linear programming Techniques, Simulation, Financial Analysis, etc. are being used worldwide for improving business performances. This paper shows a survey conducted in Vidharbha region for understanding the application of OR techniques for decision making for improving business performance. The result showed that the industries of Vidharbha region are still lacking in effective utilization of OR techniques and are relying solely on Conventional Probabilistic approach and on their Intuition for taking business decisions. The present paper is an attempt to highlight the significance of Operation Research Techniques for improving Business Performance for Small and medium industries of Vidharbha Region.

2 - Migport - Big Data Analytics and Economics of Migration

Berat Kjamili, Gerhard-Wilhelm Weber

LiBerated Social Entrepreneurship in Developing and Emerging Countries consists of a social entrepreneur using business metrics, to sustain social impact. We study differences between developing and developed countries, introducing a new OR approach to development. Commercial entrepreneurs are generally oriented to business metrics like profit, revenues and return. Instead, social entrepreneurs are non-profits or a blend with for-profit goals, generating Return to Society. In DCs, a social entrepreneurship has been uncommon. We introduce a mid-way as LiBerated Social Entrepreneur, where social businesses should be sustainable. We apply Game theory and Max-Flow - Min-Cut Theories, Schumpeter's creative destruction and Adam Smith's diversification model for our business plan. As a result, Migport started as a mobile app as a meeting point between locals and refugees. Identifying the problems of refugees by giving them a chance to talk about themselves and ensure social integration with given solutions based on database of 100 thousand people. Accuracy of data is estimated through clicks and engagement of posts. One claimed to be economist, inflation is asked next.

Multivariate Adaptive Regression Splines (MARS), Conic MARS (CMARS) and its robust version RCMARS have shown their potential for Big-Data and, recently, Small-Data. With that toolbox, we aim to further support our project. We also use Migport, Facebook, Google and Twitter analytics to forecast time series.

3 - Data Analytics and Controlling

Markus Ilg, Alexander Baumeister

Controllers today often have to justify their role in the company. According to some authors, machine learning and artificial intelligence have the potential to take over numerous controlling activities and thus make the controller superfluous. It overlooks the fact that essential new tasks arise that can neither be successfully filled by robots nor by data analysts. Consulting and analytical tasks are coming to the fore, and the digital transformation in particular is transforming the controller task area as a data supplier into that of a real business partner. However, this also requires the willingness to compensate for an existing gap in technical and methodological competence through further training. With a view to the controllers of tomorrow, the existing university programs must be revised as quickly as possible and the focus of data analysis firmly placed in the curricula. More than ever, digital transformation offers opportunities to break new ground in e-learning, online learning and blended learning.

■ TB-27

Tuesday, 10:30-12:00 - F107

Financial Optimization and Data Science in Finance

Stream: Financial Mathematics and OR
Invited session
Chair: *Duan Li*
Chair: *Qi Wu*

1 - Mean-Variance Induced Utility Maximization Framework: Risk and Potential
Duan Li

We introduce a family of mean-variance induced utility functions which keep two of the main features leading to the popularity of the mean-variance framework, namely the intuitive explanation of the objective and the availability of an easily computable optimal investment strategy. The utility functions are motivated by the equivalence between the mean-variance objective and a quadratic utility function and parametrized by a target wealth, a potential-aversion parameter and a weighting parameter. Taking the perspective of mean-variance induced utility functions naturally leads to the two measures, risk - the average weighted outcomes below the target wealth, and potential - the average weighted outcomes above the target wealth. We establish a semi-analytical solution for the optimal trading strategy under this novel framework and provide numerical examples showing that lowering the potential-aversion leads to better investment performance in terms of both risk and potential.

2 - Personas Service for Financial Scenario: Automatic Personas Construction with Interpretability on E-commercial Platform
Wen Zhang, Peng Xie, Minxue Xia, Qi Wu

The financial service industry is going through a paradigm shift from mass production to personalization. User behaviors on e-commercial platform possess massive amounts of valuable information with financial properties, therefore these data are very suitable for offering personas services. Nowadays Deep Neural Networks have achieved impressive predictive performances on a wide range of tasks, and its power of representation learning and incremental learning should be benefit for personas construction and service output, however they have also been challenged due to the lack of interpretability In this work, personas service with a novel Forest-Simulated Neural Network (FSNN) for interpretable derived features automatical construction is proposed, aiming to combine the merits of both end to end representation learning of Neural Networks and interpretability of Tree-based models. It can be embedded as a building block into any neural architectures and trained end-to-end with back-propagation. The effectiveness of the proposed method was demonstrated on six public datasets collected from Kaggle and UCI. We deployed this technology on our system based on the e-commercial data and provided the personas service which include many interpretable features with high discrimination to several insurance companies for risk prediction and risk pricing. The back-test of the online data showed the stable performance of our service.

3 - Equilibrium strategy for a multi-period mean-variance portfolio selection in a Markov regime-switching market with uncertain time-horizon and a stochastic cash flow
Zhongfei Li, Hao Ge, Xun Li

This paper considers a multi-period mean-variance portfolio selection problem with uncertain time horizon and a stochastic cash flow in a Markov regime-switching market. The random returns of risky assets and amount of the cash flow all depend on the states of a stochastic market which are assumed to follow a discrete-time Markov chain. Based on the conditional distribution of uncertain time-horizon caused by exogenous factors, we construct a more general mean-variance investment model. Within a game theoretic framework, we derive the equilibrium strategy and equilibrium value function in closed-form by applying backward induction approach. In addition, we show the expectation and variance of the terminal wealth and their relationship, and some degenerate cases are discussed. Finally, some numerical examples and sensitivity analysis are presented to illustrate equilibrium effective frontiers and the effects of uncertain time-horizon on the equilibrium strategy and equilibrium effective frontier as well as regime-switching and stochastic cash flow on the equilibrium effective frontier.

■ TB-28

Tuesday, 10:30-12:00 - G102

Finance and Banking 2

Stream: Decision Making Modeling and Risk Assessment in the Financial Sector
Invited session
Chair: *Mario Maggi*
Chair: *Matthias Horn*

1 - Real-time multi-criteria consumer credit offer optimization
Johannes Müller

Consider a customer who wishes to apply for a car loan or mortgage. The bank wants to make a small number of attractive offers, which meet the customer's needs and at the same time are profitable for the bank. The bank is also interested in managing its risk profile carefully. We present a FICO Analytic Cloud based optimization framework that computes multiple optimized credit offers in real-time, while taking into account the client's or bank's objectives, the bank's risk models, eligibility rules, and additional mathematical constraints.

2 - Automated Portfolio Rebalancing: Autonomous Erosion of Investment Performance?
Matthias Horn, Andreas Oehler

Robo-advisers enable investors to establish an automated rebalancing-strategy for a portfolio usually consisting of stocks and bonds. Since households' portfolios additionally include further frequently tradable assets like real estate funds, articles of great value, and cash(-equivalents), we analyze whether households would benefit from a service that automatically rebalances a portfolio which additionally includes the latter assets. In contrast to previous studies, this paper relies on real-world household portfolios which are derived from the German central bank's (Deutsche Bundesbank) Panel on Household Finances (PHF)-Survey. We compute the portfolio performance increase/decrease that households would have achieved by employing rebalancing strategies instead of a buy-and-hold strategy in the period from September 2010 to July 2015 and analyze whether subsamples of households with certain sociodemographic and socioeconomic characteristics would have benefited more from portfolio rebalancing than other household subsamples. The empirical analysis shows that the analyzed German households would not have benefited from an automated rebalancing service and that no subgroup of households would have significantly outperformed another subgroup in the presence of rebalancing strategies.

3 - LGD-Modelling, Stochastic Collaterals and Banking Regulation
Daniel Börstler, Sascha H. Moells

In times of increasing real estate prices the risk of mortgage loans is often underestimated. This is a severe problem that - among others - has caused the global financial crisis about 10 years ago. Against this background we analyze the impact of fluctuations in revenues from collaterals on credit risk measurement and develop a new approach incorporating such fluctuations in more risk sensitive way. Collaterals are captured by the loss given default, whereby LGD models typically assume a certain collateral value. This presumption results in an expected loss of 0, when the expected revenue from collaterals (RC=Market value*(1-Haircut)) completely covers the exposure of default (EAD). Thus, the risk of receiving a smaller amount is ignored. For heavily collateralized loans (RC>EAD) this effect cannot be compensated by realizing higher revenues in individual cases since the bank cannot claim more than the EAD. Under the Basel II accord, this aspect is covered by a 10%-floor for LGDs on portfolio level. New requirements (Dec 2017) now explicitly prescribe floors for the collateralized portion of an individual loan. Using simulation, we analyze traditional LGD approaches (incl. and excl. new requirements) regarding their predictive power for realized LGDs and present a new approach which is capable of correctly capturing the uncertainty of collateral values. Additionally, we show that the new regime results in a more accurate measurement only if a traditional approach is used.

4 - Inside the Factor Zoo: Optimizing ESG Factors with Extreme Risk Control for Goal-Driven Portfolios
Gordon Dash, Nina Kajiji

Firm managers work diligently to produce goods in a socially and environmentally sustainable manner. Although socially conscious investing is a viable and rewarding alternative for the professional investor who seeks to mitigate the risks coming from environmental, social, and corporate governance (ESG) management styles this is not always true for the naïve investor. In the absence of well-identified and persistent ESG factors, the broader question of consistent implementation remains uncertain for both naïve and some professional investors. Non-persistent factors beyond Fama-French has produced a pricing industry that many researchers refer to as the "factor zoo." Constructed on a production-theoretic framework, this research avoids the "zoo" by utilizing recent advances in network theory and artificial intelligence to construct optimized indices of the ESG policy landscape. The indices are incorporated in a multiple objective portfolio optimization model to demonstrate the relationship to the traditional mean-variance approach. The simulated performance of a non-profit's investment portfolio yields efficiently diversified ESG portfolios with stable risk-mitigated investment plans. When converted to a real-time investment setting, the model is further extended to capture option-implied CVaR goals. The results of these two extensions offers portfolio managers significant improvements when considering ESG and extreme risk control goals.

■ TB-29

Tuesday, 10:30-12:00 - C118

Big Data II

Stream: Big Data in Complex Systems
Invited session
Chair: Jiping Xing

1 - Combining Mobile Phone OD Data and Mobile Internet Usage Data to Analyse the Spatio-temporal Variations in Travel Demand in Different Time Periods
Jiping Xing, Ronghui Liu, Charisma Choudhury, Zhiyuan Liu

There is a recent trend in complementing travel survey data with new mobility-related data sources.However, those studies have primarily focused on a single data source and there are very few applications involving multi-source data fusion. The objective of this research is to investigate the relationships between travellers' mobile internet usage and the POI (Point of interest) of the trip origins and destinations. For example, we examine whether/what a congested area is associated with what, if any, particular types of POI and for what time periods. Moreover, users with different proportion of internet usage group show different preferences for types of origin and destination as well.The spatial and temporal analysis would be conducted. The spatial analysis main focus on the relationship between traffic production and traffic attraction by distinguishing the difference of land use types, and the temporal analysis try to present travel demand in the different time periods. Influencing factor weight analysis method could be used to understand the socio-demographic factors influencing travel behaviour. Each category from mobile phone usage data could be viewed as the influencing factor in analysing of travel demand. The significance factor could be extracted from those influence factor. Furthermore, we develop a predictive model based on machine learning method to predict areas which attract traffic and cause traffic congestion.

2 - MaSU : An Information Based Technique for Visualizing the Properties of Your Data
Tal Sheldon, Alon Patelsky, Gail Gilboa Freedman

We introduce a technique for representing high-dimensional data as a network in a much lower dimensional space. We call the technique MaSU as it is based on the Matrix of the Symmetric-Uncertainty values between any couple of features in the data set.

The main contribution of MaSU is that it visualizes mathematical properties of any data set, by a single graph that is easy to capture by a human eye. Moreover, in contrast with other standard methodologies for exploratory description of data – such us demonstrating the correlations of its features – MaSU takes an information-theory approach which does not need to assume linear relations between the features, making it more robust. In addition to giving a clear visualization, MaSU also gives a solution to the feature selection problem, which is a fundamental challenge in Machine Learning.

MaSU combines information-theory and network-science methods. It takes tabular data set, where each row represents an instance and each column represents a feature (property of the instance), and produces a network, of which the nodes represent a subset of the features, and the weight of the edges represent Symmetric-Uncertainty among these features.

We demonstrate the usefulness of MaSU for a variety of publicly available data sets. For each data-set, we execute MaSU technique in a Python program that generates a subset of selected features, along with a visualization of these features and their mutual information as a network.

3 - Analysis of Tabular Data based on Graph Neural Network
Seungyeon Lee, Minyoung Park, Dohyun (Norman) Kim

In many areas such as computer vision, social networks, and molecular chemistry, the relationships between data can be represented as a graph, which is a data structure that consists of nodes representing observations and links representing their relationships. Graphs can model complex systems by considering the relationships between data and feature information simultaneously. Recently, graph neural networks (GNNs), deep learning-based methods for graph analysis, have been widely used due to their robust performance. However, GNNs cannot be applied to tabular data, most commonly used in most multivariate data analysis, because they cannot easily express the relationships between observations. To effectively use tabular data in GNNs, we propose a GNN algorithm based on tabular data for node classification. The proposed method is compared to existing tabular data based approaches. Experimental results show the proposed approach performs better than tabular data based approaches regardless of the data sets.

■ TB-30

Tuesday, 10:30-12:00 - C007

Optimization of Machine Learning Models

Stream: Data Science Meets Optimization
Invited session
Chair: Dimitri Papadimitriou

1 - Feature Selection Using Variable Neighborhood Search and K-Nearest Neighbors Algorithm
Gen-han Wu, Yung-Hsun Tsai

In this study, we proposed variable neighborhood search and k-nearest neighbors algorithm to solve the problem of feature selection. Variable neighborhood search is used to pick out a subset of features and k-nearest neighbors algorithm is applied to evaluate the classification performance of the solution of this subset. It is expected to pick out a subset of feature that can effectively classify the data with a small number of features. This study first conducts a series of parametric experiments on the nearest neighbor method, and then picks out a combination of parameters that can have good classification performance in most data sets. Then the algorithm is tested in data sets with different sizes. The experimental results compared with previous studies shows that the proposed method can achieve similar or even better classification performance in most data sets than in previous studies.

2 - Top-N food item recommender system based on mutual information and entropy weighting
Ante Ivancic, Argyris Kanellopoulos

Rising incomes and urbanization lead to unhealthy dietary changes, which can increase the incidence of chronic diseases. Mathematical diet optimization tackles the challenge of identifying the optimal combination of food items recorded in a consumer's purchase history to meet a particular objective (e.g. nutritional adequacy) under a set of predefined constraints. However, meeting an objective is often impossible without introducing new, and likely preferable food items, which is a significant challenge that has not been adequately tackled. Most current methods are based on some form of the majority vote, which is overly simplistic. We propose a recommendation system for adding new food items in an informative way, by leveraging concepts from information theory, namely the information entropy and mutual information. The information entropy represents the average information content of a random variable, and serves as a weighting function which transforms the input data into a more suitable representation. Mutual information serves as a general measure of dependence between two random variables, and is leveraged as the similarity measure between all pairs of food items, thereby giving rise to a complete food item graph that serves as the basis for the recommendation of the top N likely preferable food items not recorded in a consumer's purchase history.

3 - Dual Decomposition for Ensuring Data Privacy in Capacity Sharing
Utku Karaca, Ilker Birbil

We consider a capacity sharing problem where resources are allocated to multiple parties. Though the parties agree to collaborate, they are also concerned about keeping their sensitive data (revenues, costs, capacity usages) private. There are many studies in the literature on collaborative decision making through information sharing. However, these studies do not consider data privacy. In this study, we propose a dual decomposition approach to distribute the shared capacities to the involved parties in such a way that the parties end up accessing only to their own data while collectively solving the overall problem. In case the solutions need to be shared among the parties, we also show that these solutions can be masked with elementary transformations. We conclude our work with a simulation study on several application scenarios.

4 - Robust Optimization of Neural Network Models
Dimitri Papadimitriou

Learning from uncertain data, e.g., from noisy/perturbed input and/or erroneous/ imprecise labels, yields to consider robust learning methods to prevent model overfitting. The goal of robust learning is to provide for formal performance guarantees on the robustness of the trained model under stated uncertain situations/ conditions (known unknowns) by means of various regularization methods. Regularization refers to a broad set of techniques such as the addition of a penalty term in the objective function to control/adjust its fluctuations, the inclusion of constraints to learnable parameters (weights, structure, etc.), that aim at decreasing the testing/generalization error (variance of the model) while keeping the training error (bias of the model) unaffected. Nowadays, regularization techniques are being investigated where these additional terms/constraints go well beyond linear deterministic regularizers such as parameters L1/L2 norm-based regularization or their convex combination (a.k.a. elastic net regularization). These techniques include L_p,q regularizers, first-order regularizers (I/O Jacobian of the model) and regularization terms/functions that share their Lipschitz continuity properties with those of the activation functions. In this paper, we study the accuracy gain these methods yield against the computational complexity in time they involve at training phase. Then, we formalize how the regularization parameter(s) can be dynamically adjusted at training time.

■ TB-31

Tuesday, 10:30-12:00 - G108

Vehicle routing in healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Melanie Reuter-Oppermann

1 - A MILP model for ambulance dispatching and relocation considering a time-preparedness metric
Maria Eugénia Captivo, Ana Sofia Carvalho, Inês Marques

This work focuses on ambulances' action to respond to urgent emergency requests. The decision-making process plays a very important role to help Emergency Medical Service (EMS) managers in strategic, tactical and operational decisions. We focus on the operational level by solving the ambulance dispatching and relocation problems. Ambulance dispatching decisions assign ambulances to emergencies and the relocation problem decides to which base available ambulances should be (re)assigned. A time-preparedness metric is considered and calculated for a fleet of available ambulances at the current time period. To improve effectiveness and efficiency in the EMS response, a mathematical model for an integrated optimization approach for the dispatching and relocation problems is proposed. The main goal is to ensure a good system's response for emergencies on the current period and a good system's preparedness for the future. It is crucial not to have current uncovered emergencies and to provide a good service level within the maximum response time. Experiments are performed using EMS data from Lisbon, Portugal, where solving these problems is still a handmade task. The optimization approach is adapted to compare the proposed strategy with the current Portuguese EMS strategy which dispatches the closest available ambulance and relocates ambulances to their home bases. Results highlight the potential of the model and of the proposed strategy to be applied in real-time contexts.

2 - A GRASP-based decision support system for the Home Health Care Routing and Scheduling Problem
Carlos Lamas-Fernandez, Thomas Monks

The Home Health Care Routing and Scheduling Problem (HHCRSP) consists in assigning routes and schedules to nurses that deliver health care services to patients at their homes. A varied range of hard and soft constraints such as time windows, synchronisation of nurses, skill mix or patient and nurse preferences make this problem particularly difficult to solve by hand. However, this is a challenge faced by many community nursing teams on a daily basis.

In this work we present an open-source decision support system (DSS) that aims to help solving this problem in a practical way. Our DSS is based on a Greedy Randomised Adaptive Search Procedure (GRASP) that solves a multi-objective HHCRSP, providing a range of high quality solutions in a short time and according to different criteria. The DSS is also linked with open source maps and an interactive reporting system that allows to visualise the solution of the HHCRSP problem in an intuitive way, which can help planners both save time and achieve more efficient plans for their everyday operations.

Our preliminary results working with local home health care teams in the south of England suggest that this is a promising approach given its flexibility to include practical constraints and its speed. Furthermore, we expect that its availability and independence of commercial solvers will help reaching more teams in the future.

3 - Home Chemotherapy Planning: An Integrated Production Scheduling and Multi-Trip Vehicle Routing Problem
Yasemin Arda, Diego Cattaruzza, Véronique François, Maxime Ogier

Home chemotherapy (HC) services aim to assist cancer patients enabling them to remain comfortable at home. This is currently a rising trend, and it should be encouraged when the patient's conditions are favorable. HC services imply both the production and the administration of drugs to patients. These activities are run in parallel and must be carefully synchronized due to short lifespan of drugs and limited resources. In order to efficiently plan these activities at the operational level, two well-known and hard problems, scheduling and routing, need to be solved as a whole, rising challenging synchronization issues. We consider a set of patients that must be visited by a set of nurses for administration of personalized drugs. Nurses come back to the hospital in order to get newly produced drugs thus perform multiple serving trips. The drug is produced right before delivery by a set of the technicians in the hospital pharmacy. We propose to use a large neighborhood search heuristic that iteratively removes and reinserts operations to create new solutions. Three destroy and recreate operators are considered: 1) production operations are removed and reinserted 2) drug administration operations are removed and reinserted 3) both types of operations are removed and reinserted. Ad-hoc mathematical programming based operators are developed to re-optimize the current solution. The algorithm is tested on new instances created based on discussion with hospitals in Belgium.

4 - Multi-Criteria Approaches for Planning Patient Transports in Germany
Melanie Reuter-Oppermann, Andrea Raith

Emergency medical service (EMS) systems in Germany are not only responsible for emergency rescues but also for transporting patients, between, to or from hospitals, if the attendance of an emergency medical assistant is necessary. Even if for many EMS regions a significant percentage of tasks is known in advance, trips are usually not planned at present, especially not automatically, while more and more dispatchers would appreciate software support. One of the main challenges are the competing objectives. While the driving times are to be minimised, so are the waiting times for the patients due to late arrivals of the transport ambulances. In addition, as many tasks as possible should be fulfilled. Also, workload balancing is of interest for many EMS regions. We present and compare a dial-a-ride formulation and (online) heuristics for deterministic as well as dynamic transport planning to handle the known as well as the short-term tasks. We test the approaches using real-world instances from German coordination centres and analyse the impact of considering two or objectives. The long-term goal is to build a decision support tool that assists the dispatcher with planning patient transports.

■ TB-32

Tuesday, 10:30-12:00 - G109

Sports and uncertainty

Stream: OR in Sports
Invited session
Chair: *Dries Goossens*
Chair: *John Trono*

1 - A stochastic programming approach for scheduling round-robin sport leagues
Xiajie Yi, Dries Goossens

A stable sports league schedule should be well-prepared for unexpected events (uncertainty). To design such stable schedule for round-robin sports leagues, we develop a two-stage scenario-based stochastic programming approach. An initial schedule is usually published before the start of the season. During the season, uncertain events like bad weather can occur, leading to the rescheduling or even the cancelation of games. The schedule that was effectively played is the realized schedule, which can be known only at the end of the season. Ranking difference, i.e., the extent to which a fair ranking can be made at each round in the season, is applied as a quality measure to evaluate the schedule. While our method is generally applicable, we study soccer as a typical round-robin sport. Scenarios and their probabilities are developed from historical data of ten major European soccer leagues (2002-2017). The number of available extra rounds and their positions are decided in the first stage, while rescheduling postponed games is done in the second stage. We have two settings for the number of extra rounds, which is either given or determined by our stochastic model via a cost ratio. We validate our results on 4000 out-of-sample instances, with up to 15 postponed games per season. The results show that the position of extra rounds shifts depending on the number of extra rounds, and that the cost ratio has a powerful influence on the number of extra rounds decided by the model.

2 - Gradient-Boosted Multinomial Logit models for horserace outcome modeling
David Edelman

This research combines the well-established efficacy of Gradient Boosting as an approach in Machine Learning with the traditional 'Bolton-Chapman' Multinomial/Conditional Logit approach to the modeling of horserace outcomes. Some little-known 'tricks' are discussed for performing such analyses with existing packages in the software package R, as will be demonstrated by a Case Study from French Harness racing. Additionally, two methods for remedying the discontinuity issue arising from the most commonly applied ('stump') version of Gradient Boosting will be presented, and the resulting improvement in model performance on data from the Case Study exhibited.

3 - Strategies for Surviving an NFL Knock-Out Pool
John Trono

Knock-out pools, sometimes also referred to as elimination pools, have gained significant popularity this century. To advance in such a pool, a team must be chosen each week, and they must win their next game, otherwise, that participant is knocked out of the pool. (Also, that team cannot be selected again, by that participant, during that regular season.) The participant who lasts the longest in the pool wins it; several participants may have to split the 'prize' if they survive the entire, regular season (without getting knocked out). Several fairly successful strategies to survive in such a pool will be presented, and evaluated over the past 16 NFL seasons. All of these approaches rely on a recently devised, quantitative prediction formula that determines the likelihood of future game outcomes. Those probabilistic quantities are used to guide the next week's team selection.

4 - Finding equilibrium strategies for rallies in net sports
Rónán Rian Carl Richter, Florian Johannes Fischer, Susanne Hoffmeister, Jörg Rambau

A net sport usually involves two teams playing a sequence of rallies. The winner of a match is then determined by the first team to win a certain number of rallies with a sufficiently large lead. A rally starts with one team serving. Thereafter, the possession of the ball (or shuttlecock, etc.) alternates between the opponents until one of them makes a fault and thereby loses the point. These faults may occur when trying to receive the ball or during an attack. Typically, both of these actions allow for an execution with more or less risk. I.e. by choosing actions that are harder to perform, a team can increase the opponent's probability of a fault in the next stage while at the same time increasing the probability of a failure of the own current hit. In this talk, a model for a single rally in a net sport game will be presented. This model will only take use of two parameters modeling the strength of the teams. Strategy choices will be expressed by a single value per team, that represents the degree of riskiness of the chosen action. First analytical and numerical results for equilibrium combinations of the strategies of the teams in this model will be presented. It will be outlined, that, even though we created a very coarse model, equilibria are not obvious for all parameters.

■ TB-33

Tuesday, 10:30-12:00 - Q005

Modelling and Optimisation in Industrial Organisation II

Stream: Mathematical Modelling
Invited session
Chair: Ioanna Mitrofani

1 - Decentralized rationing problems and the proportional rule
Josep Maria Izquierdo

A standard rationing situation is an allocation problem in which a set of agents claim to some amount of a scarce resource. Bankruptcy situations or agents competing for some limited budget are examples of such situations. An allocation rule assigns an amount to each agent that do not exceed her claim. In this paper we suppose that agents are distributed in groups and we allocate the resource not directly but using a two-stage procedure: first, distributing the resource among the groups and, second, dividing it among their members. We call these situations decentralized rationing problems.

We study the properties that satisfy classical rationing rules when they are applied in the decentralized setting. We focus on the property of equal treatment of equals, which states that two agents with equal claims should receive the same. We show (Theorem 1) that in the decentralized setting there is only one rule that satisfies this property: it is the decentralized proportional rule.

We also study whether the application of a rule is the same regardless the resource is distributed directly to agents or indirectly through groups. When this happens, we say the rule is decentralized consistent. In Theorem 2, we prove that decentralized consistency is enough to characterize the proportional rule. It is also pointed out that decentralized consistency is equivalent to other concepts studied in the literature, such as strategyproofness and non-manipulability.

2 - Knowledge externalities as a base of agents' behavior
Ilia Garmashov, Alexei Korolev

We consider the dynamics in the networks with production and externalities of knowledge, built by Professor V. Matveenko and A. Korolev based on the transfer a simple two-period Romer model to the network. The concept of the Jacobian Nash equilibrium used in the models of Lucas and Romer is applied. At the same time, the influence of exogenous factors on the behavior of agents in network, which was initially in equilibrium, is studied. The unification of some network agents with agents of another net, which was also initially in equilibrium, is taken as an exogenous factor. We study the transitional dynamics and changes in equilibrium conditions. Changes in the threshold of activity and hyperactivity of agents as a result of connecting agents from different networks are also considered. The influence of externalities on the behavior of agents, in particular, on the rate of transition to a new stable equilibrium is studied. An interpretation of the obtained results is proposed for modeling the spread of fear in the human society.

3 - Prioritisation-driven logistics planning in disaster relief
Douglas Alem, Tolga Bektas

We consider a particular location-allocation problem arising in humanitarian logistics that entails establishing response facilities and prepositioning relief aid. In contrast to the common monetary-driven objectives often used in the relevant literature, we offer a different perspective that is primarily based on prioritisation, which is reflected both in the objective and the structure of the problem. To this end, we propose a way to quantify the prioritisation of vulnerable communities according to their income shortfall.

4 - A fuzzy logic DSS for scope optimisation in industrial maintenance projects based on reliability targets
Ioanna Mitrofani, Dimitrios Emiris

Maintenance projects in the process industry are key to the operational viability of a plant. A common, fundamental challenge faced is the optimisation of the project scope, so as to include the equipment that can only be maintained during the shutdown period while excluding equipment that exhibits decreased failure risk. In the present approach, we develop a decision-support mechanism, that employs fuzzy logic tools to derive a criticality index for maintenance for each candidate equipment. The mechanism encompasses an augmented set of industry-related criteria, such as maintainability, reliability, criticality etc. The aim of our approach is to decrease the uncertainty, increase the reliability and availability of systems, especially in complex industrial systems. Our approach gives important insight on maintenance techniques and sheds new light on alternative scope definition and optimisation approaches. That system supports decisions and implementations of Shutdown-Turnaround-Outage Maintenance strategy, which is preferred by the majority of industries with large maintenance projects. We prove the validity of our approach by comparing and contrasting with other deterministic tools and clearly display the benefits of infusing fuzzy-logic models to support such decisions.

■ TB-34

Tuesday, 10:30-12:00 - Q006

Multiobjective Optimization and Real World Applications I

Stream: Multiple Criteria Decision Making and Optimization (contributed)
Contributed session
Chair: Guillermo Cabrera-Guerrero

1 - Multiobjective Linear Optimization on Partial Permutations With Applications
Liudmyla Koliechkina, Oksana Pichugina

Approaches to multiobjective linear optimization (multiobjective LO, MLO) on a combinatorial configuration of partial permutations (PPC) is investigated by graph-theoretic tools. Generally, difficulties in optimization on PPC by standard discrete optimization techniques, such as cutting-plane and branch&bound, are caused by the following reasons: a) a presence of feasible points in an interior of a convex hull of PPC and its faces; b) a distinction of the feasible domain from the corresponding grid. This leads to the need to develop specific approaches to LO, MLO on PPC. We present a graph-theoretic approach to LO on PPC, termed Grid Method (GM), and use it as a basis of our MLO-method. An implementation of GM assumes a transition from PPC to considering a permutation configuration (PC) with the same induced set as PPC and performing LO on PC. Unlike PPC, any PC coincides with a vertex set of its convex hull making it possible to solve LOP conducting a directed search (DS) on a skeleton graph of a permutohedron. In GM, DS is performed on a directed grid graph (GG), which is singled out from the corresponding transposition graph. GM uses solutions of an unconstrained linear problem on PC and GG, lexicographic ordering of GG-nodes, simplicity of constructing and analyzing a neighborhood of any GG-node allowing considering minor part of PC. The complexity of GM is polynomial and defined by the induced set cardinality, grid dimension, and node code length.

2 - A VNS approach for the Freight Transportation Supplier Selection Problem
Rukiye Kaya, Said Salhi, Virginia Spiegler

A VNS approach for the Freight Transportation Supplier Selection Problem Rukiye Kaya, Said Salhi and Virginia Spiegler Centre for Logistics & Heuristic Optimisation (CLHO), Kent Business School, University of Kent, UK

Supplier selection and scheduling problems have been investigated independently in many studies. However, there is a lack of integration especially in the area of time critical freight logistics, also known as contingency logistics, for third party logistic providers. In this talk, we shall concentrate on the first stage by addressing the problem of supplier selection while highlighting the impact that may have on the scheduling part. We address this multi-criteria related problem by introducing new features within VNS inspired by some of the attributes of the known MCDM approaches such as AHP, TOPSIS and VIKOR. We will assess the effectiveness of our methodology by conducting experiments using the three above methods, classical VNS and the proposed enhanced version. Interesting results are reported and potential challenges that could arise when integrating this phase with the scheduling phase are also highlighted.

3 - A multi-objective approach to support scheduling wine grape harvesting operations

Sergio Maturana, Mauricio Varas, Franco Basso, David Osorio, Raul Pezoa

Operations research and Analytics are increasingly being used to support decision making in wine production operations. However, there have been very few applications of multi-objective optimization methods in this industry despite the fact that it may be important to consider different perspectives when planning wine supply chain operations. In this paper, we present a novel multi-objective mixed-integer linear programming model to support scheduling wine grape harvesting operations assuming the field manager and the oenologist have conflicting objectives, which is usually the case. The proposed model considers the opposing nature of grape harvesting operational cost minimization and wine grape quality maximization, subject to several constraints, such as grape requirements and intra-period routing decisions. In this operational environment, a posteriori or generation methods are inadequate from a practical point of view. Therefore, we analyze how interactive methods can be used to support the negotiation process between the field manager and the oenologist. Based on a real harvesting situation, we developed a negotiation protocol that, using the STEM method, can be used to support scheduling wine grape harvest operations considering both the field manager's and oenologist's objectives. We present some early tests of this protocol.

■ TB-35

Tuesday, 10:30-12:00 - Q009

Game Theoretical models and Applications III

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Marco Dall'Aglio*

1 - Stable matching with an entrance criterion for teams

Shoshana Anily, Nitsan Perach

In this talk we generalize the results on the assignment of students to dormitories at the Technion, Israel Institute of Technology, under an entrance criterion, to the case where students may apply in groups (thereafter called teams), where each team consists of at least one student. A team-application means that the students of any given team, ask to be assigned to the same dormitory-group. More specifically, students of the same team prefer living off-campus rather than living in different dormitory-groups.

The underlying assumption in our model is that the dormitory-groups share a common preference over the teams, which is given by a strictly increasing ranking of the teams' credit scores. We adjust the definition of a quasi-stable outcome to incorporate team applications, and show that a quasi-stable outcome, always exists. Furthermore, an algorithm that finds all the quasi-stable outcomes, is presented. Apparently, some of the properties of the model for single students, continue to hold also under the team application model. Finally, we consider the incentive compatibility property of the outcomes generated by the proposed algorithm, and show, in particular, that the algorithm that produces a specific quasi-stable outcome, is manipulation-proof, i.e., no subset of teams can gain by misrepresenting their preferences over the dormitory-groups.

2 - Social simple games: parameters and properties under connectivity restrictions

Maria Serna, Maria J. Blesa, Eline van Hove

A simple game is the simplest kind of cooperative game in which the value of a coalition is either 1, wins, or 0, loses. The characteristic function of a simple game is required to be monotonic. However in simple games it is assumed that any coalition can be formed. In a realistic scenario we can assume that a social network reflects the interactions among the players. Some structural properties of the social network might limit the possible coalitions or forbid some winning coalitions to form. We introduce the class of "social simple games", here the players are related through a graph, representing their social network. We present some new classes of simple games refined by connectivity restrictions over the coalitions or the winning coalitions. These classes of simple games are not necessary monotonic.

We study some properties and characterize the computational complexity of the corresponding problems on simple games over these new classes. We look at game properties (monotonicity, properness), measures (length and width), values (Shapley-Shubik and Banzhaf) and other properties of coalitions and players. Finally, we also present some related open problems.

This research has been partially supported by TIN2017-86727-C2-1-R (GRAMM).

3 - Fair division solutions to judicial problems The CREA project.

Marco Dall'Aglio

In this talk we will discuss new fair division procedures specifically designed to propose an equitable distribution between parties involved in family law disputes (heredities and divorces), and to reach an out-of-court agreement among them. Typically, fair division procedures require agents to express their personal preference on the disputed assets. Those preferences can differ from the goods' market values but cannot be totally disconnected from them. The algorithms that we propose express agents' utilities as distortion of the market prices and return allocations that maximize the social welfare of the allocation, while maintaining equal or proportional market values of the proposed shares. Those algorithms are being applied in the context of the Conflict Resolution through Equitative Algorithms (CREA) project funded by the European Union's Horizon 2020 research and innovation programme, aiming at introducing new mechanisms of dispute resolution in legal contexts. The proposed solutions also ignite new research questions on the optimality properties of the proposed solution, together with an analysis of their robustness against manipulations. Disclaimer: This contribution has been produced with the financial support of the Justice Programme of the European Union. The contents of this contribution are the sole responsibility of the authors and can in no way be taken to reflect the views of the European Commission

■ TB-36

Tuesday, 10:30-12:00 - Q010

Arc Routing Problems

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Karl Doerner*

1 - Coordination of vehicles in snow removal

Roghayeh Hajizadeh, Kaj Holmberg

Snow removal is an important problem in some countries. A number of streets in a city need to be cleared of snow by a limited number of vehicles within a certain time. We have formulated the problem as a very large mixed integer programming problem, which is practically unsolvable. We have some relaxations of the model that yield rather good lower bounds in rather short time. In order to find a feasible solution and an upper bound, first we break down the work into smaller tasks.

A simplification is to solve the weighted k-Chinese postman problem to find which streets a vehicle shall take care of. We have also considered the problem facing a single vehicle with all details. This problem can be reformulated to an asymmetric traveling salesman problem in an extended graph, and we have a heuristic for finding a feasible solution. Now, we discuss combined solution approaches and coordination of the vehicles to find a feasible solution for the original problem including all details. We use an iterative procedure to combine the tours, based on the tools mentioned above, and a procedure for constructive feedback from the solutions.

2 - The Capacitated Arc Routing Problem with Vehicle Dependence
Hugo Perez, Jonas Velasco, Luis E. Urban-Rivero

The Capacitated Arc Routing Problem (CARP) is a combinatorial optimization problem that consists of satisfying demands for services or products on certain streets of a network, by means of a fleet of vehicles, minimizing the total cost of travel involved. This problem has been studied extensively for many years due to the fact that it can be applied to real cases such as garbage collection, maintenance of streets, reading of electric meters, delivery of the postal service, among others. In this work, we present a new generalization of the CARP called CARP-VD (Capacitated Arc Routing Problem with Vehicle Dependence) as a Mixed Integer Lineal Programming model. This model considers that the costs to satisfy the demand depend on the type of vehicle chosen from a heterogeneous fleet on an undirected graph. We propose a constructive heuristic approach to solve the problem that consist of two stages: for the first stage, the problem is solved in order to assign edges to vehicles that not exceeding its capacity and in the second stage, the routes are constructed for each vehicle. In the computational experiments, the results on several instances obtained from the literature, show that the proposed constructive heuristic obtains good quality solutions in short computation time in comparison with others approaches.

3 - Multi-vehicle Prize Collecting Arc Routing for Connectivity Problem
Vahid Akbari, Sibel Salman

For effective disaster response, roads should be cleared or repaired to provide accessibility and relief services to the affected people in shortest time. We study an arc routing problem that aims to regain the connectivity of the road network components by clearing a subset of the blocked roads. In this problem, we maximize the total prize gained by reconnecting disconnected network components within a specified time limit. The solution should determine the coordinated routes of each work troop starting at a depot node such that none of the closed roads can be traversed unless their unblocking/clearing procedure is finished. We develop an exact Mixed Integer Program (MIP) and a matheuristic method. The matheuristic solves single vehicle problems sequentially with updated prizes. To obtain an upper bound, we first relax the timing elements in the exact formulation and then solve its relaxed MIP, which decomposes into single vehicle problems, by Lagrangian Relaxation. We show the effectiveness of the proposed methods computationally on both random Euclidean and Istanbul road network data generated with respect to predicted earthquake scenarios.

4 - Metaheuristics for the Multi-objective and Periodic Node Edge, Arc Routing Problem considering Costs and Route Inconsistency
Karl Doerner, Georg Erwin Adrian Fröhlich

Security problems can have many different facets - cash in transit operations (e.g. collecting or delivering cash), guard duties (e.g. personal protection, patrolling areas, custody of buildings), or military operations (e.g. movement of troops, patrolling territory) - for which the considered aspects are usually the costs and security of a solution. This research focusses on a multi-objective and periodic node, edge, arc routing problem (MO-P-NEARP). This covers a mix of patrolling streets with intermittent stationary guard duties. The two objectives that we study are costs and route inconsistency. Route inconsistency measures how often arcs or edges are used within given periods (not counting service), and whether the sequences, in which the services take place, have similar subsequences. The MO-P-NEARP is converted to a VRP-like problem. For the latter three different multi-objective frameworks - multi-directional local search (MDLS), ϵ-constraint heuristic (ϵ-CH), and ϵ-box-splitting heuristic (ϵ-BSH) - are used sharing an underlying adaptive large neighborhood search (ALNS). The ALNS has been tested for the single-objective version with respect to costs on several benchmark sets (BHW, CBMix, DI-NEARP, MGGDB) and delivered results close to the best published ones. For the multi-objective frameworks MDLS, ϵ-CH, and ϵ-BSH have been compared on the MGGDB instances. Furthermore, they have been tested on real world instances based on Vienna.

■ TB-37
Tuesday, 10:30-12:00 - Q011

Scheduling with Resource Constraints: Machine Scheduling

Stream: Scheduling with Resource Constraints
Invited session
Chair: Pedro Castro
Chair: *Miriam Zacharias*

1 - Flowshop scheduling with learning-effect and job-rejection
Baruch Mor, Gur Mosheiov

We study scheduling problems on a proportionate flowshop. Three objective functions are considered: minimum makespan, minimum total completion time and minimum total load. We consider a learning process, thus the processing time of a job processed later in sequence is reduced. The scheduler has the option of job rejection, i.e., he may process only a subset of the jobs, and be penalized for the rejected jobs. An upper bound on the total permitted rejection cost is assumed. Since the single machine versions of these problems were shown to be NP-hard, we focus on the introduction of pseudo-polynomial dynamic programming algorithms, indicating that the problems are NP-hard in the ordinary sense. We provide an extensive numerical study verifying that the proposed solution algorithms are efficient for medium size instances.

2 - Machine Learning in Hybrid Flow Shop Scheduling with Unrelated Machines
Miriam Zacharias, Annika Tonnius, Johannes Gottschling

Hybrid flow shop (HFS) problems are often encountered in real world production systems. Despite their practical relevance, few generic methods exist to solve HFS problems. Instead, many approaches focus on two-stage problems or apply simple dispatching rules. Moreover, many authors assume identical parallel machines, which reduces the complexity of machine assignments. If a real world case is studied, solution methods are often customized. Most common decomposition approaches are critical-path related or focus on possible permutations of job indices while utilizing simple machine assignment rules. Lately, machine learning (ML) has been applied to different scheduling problems. A common application is the selection of best dispatching rules based on the state of system parameters. We propose an alternative ML-based approach to makespan or flowtime minimization that is suitable for different HFS configurations. To speed up the scheduling process, we apply ML in one step of our solution method: We train Neural Networks (NN) and Support Vector Machines (SVM) with optimal machine assignments and makespan or flowtime values for fixed batch sizes. Afterwards, we use the trained NN and SVM to predict optimal makespan or flowtime values and machine assignments for all partial job sequences (batches) based on a given processing time matrix. Only sequences with close-to-optimal makespan values are evaluated further to determine a final machine assignment and overall sequence.

3 - A local search for the Job-Shop Scheduling Problem with Constraint Programming
Matthieu Gondran, Philippe Lacomme, Eric Bourreau

The Job-shop Scheduling Problem (JSP) is a well-known NP-hard problem modeled by a disjunctive graph. The objective is to schedule all operations and to minimize the finishing time of the latest one. A solution of the JSP is defined by the starting times of each operation. Best metaheuristics, solving the JSP, use an indirect representation where the solutions are encoded as Bierwirth's vectors [2] ; and a mapping function based on a longest path algorithm is used to decode tge vectors. The advantage of this schema is to work on a coding space that is smaller than the solution space. The objective of this paper is to introduce a new mapping function based on a Constraint Programming (CP) model. The CP model offers both to compute a solution and to define a local search process. An initial vector is randomly generated and the CP model is used as a local search to find a new vector closed to the initial one thanks to the search tree. The distance between the initial vector and the new one is limited. CP model is based on a model coming from disjunctive graph and has been proved efficient defining a new way in local search mechanism. The proposed method is benchmarked on the Lawrence's instances using a basic GRASPxELS appraoch and obtains optimal or nearly optimal solutions to the instances from LA01 to LA10. Ref. [2] C. Bierwirth,'A generalized permutation approach to job shop scheduling with genetic algorithms',Oper.-Res.-Spektrum,vol.17,no2-3,p.87-92,199

4 - Discrete and continuous-time formulations for preemptive scheduling
Pedro Castro, Iiro Harjunkoski, Ignacio Grossmann

We propose new mixed-integer linear programming (MILP) formulations for handling preemption in flexible flowshops. Preemption refers to the possibility of interrupting the execution of a task when encountering a break, located at a pre-defined time window, assuming that the task continues immediately after the end of the break. We rely on Generalized Disjunctive Programming to derive the constraints for the continuous-time formulations and on a compact convex hull reformulation to make them computationally efficient. We investigate the general precedence and multiple time grids concepts of time representation. We also generalize a well-known discrete-time formulation from Process Systems Engineering that relies on the Resource-Task Network representation, by changing its parameters. Validation and comparison of the mathematical formulations is done through the solution of sixteen benchmark problems, involving instances with one to four sets of breaks. The results show that general precedence formulation is computationally more effective for flexible flowshops, being beaten by the discrete-time approach when considering common rather than machine-dependent breaks. For single stage plants with parallel units, the multiple time grid formulation prevails.

■ TB-38
Tuesday, 10:30-12:00 - Q012

Decision Aiding Methods 3

Stream: Multiple Criteria Decision Aid
Invited session
Chair: *Salvatore Corrente*
Chair: *Milosz Kadzinski*
Chair: *James Liou*

1 - Assessing coastal municipalities to implement sustainable marine itineraries: A MCDA sorting tool based on ELECTRE-Tri-C
Olga Porro, Mónica Sánchez, Nuria Agell

A Via Brava (VB) is a marine itinerary which is protected by buoys and dedicated to recreational, educational and environmental protection activities. There are currently 26 coastal towns in Catalonia with a VB, representing a total of 25,7 km. Since its foundation, more than 5.400 people have registered to some of the offered activities. Currently, the VB management team's strategic priority is the implementation of new itineraries in new coastal locations where the implementation of a VB fits best with the coastal town's profile and where the economic, environmental and social impact of VB can be better leveraged. Specifically, they seek to expand to the Balearic Islands.

The purpose of this study is to adapt the decision-aiding sorting method ELECTR-Tri-C and combine it with hesitant fuzzy sets for grouping towns in three categories according to their potential and readiness to implement a VB in its territory. The model is constructed with the interaction of the authors as analysts with the management team, local actors of the public sector and marine environmental experts. ELECTRE-Tri-C has already been used to support decision making in areas with high impact in sustainability. Our contribution represents a critical multi-criteria decision aiding tool for the strategic planning of Vies Braves, an enterprise contributing to make sustainable development a reality.

2 - ELECTRE Score: a first Outranking Based Scoring Method
Salvatore Greco, José Rui Figueira, Bernard Roy

We present an outranking method to assign a score to a set of actions. It is a method of the Electre family methods, and we will call it ELECTRE -Score. Differently from the Multi-Attribute Value Theory (MAVT) methods, ELECTRE-Score does not construct a value function for each criterion, and then proceed to the aggregation into a single value. It, rather, makes use of an outranking relation to make a comparison with reference sets of actions, to which we assign a score with a deck of card method, and proposes a score range for each action, instead of a single value. Given the fragility of a single punctual score, the interval score assigned by the proposed method seems a more robust way of proceeding. The sets of references actions satisfy the same properties of ELECTRE Tri-nB. The fact of being able to use outranking relations makes it also possible to take into account the imperfect knowledge of data and to avoid systematic compensatory effects. Some fundamental theoretical results guaranteeing the consistency of the method and an illustrative example are provided.

3 - An improved version of the deck of cards method to build evaluation scales
Salvatore Corrente, José Rui Figueira, Salvatore Greco

We present an improved version of the deck of the cards method to render the construction of the ratio and interval scales more "accurate". The improvement is due to the fact that we take into account more preference information provided by the decision-maker. This preference information enriches the way of modeling the difference in the evaluation between two consecutive levels of a scale. Indeed, differently from the classic SRF method, we do not consider the number of blank cards to be included between consecutive levels of objects, criteria, scale levels only, but we consider a full pairwise comparison table. This table can contain imprecise or missing information. In case the preference information is not consistent, we provide methodologies to help the decision-maker to build her/his evaluations in a co-constructive way by interaction with an analyst allowing revising her/his preference judgments. The method is illustrated through a didactic example in which it is applied to the Choquet integral preference model.

4 - A hybrid MCDM-based FMEA model to identify the critical failure modes for manufacturing
James Liou, Huai-Wei Lo, William Shiue

How to effectively identify the critical failure modes of the equipment and to develop an improvement plan is an important task for manufacturing. Recently, multiple criteria decision-making (MCDM) combines with failure modes and effect analysis (FMEA) is an effectively tool to assess the primary failure modes and risks. However, the ranking of the fault pattern generated from each MCDM method is somewhat inconsistent. This study proposes an integrated risk assessment model, which combines several techniques in FMEA model to generate the final ranking of failure modes. Expected costs and environmental protection indicators are included in the model to reflect the sustainability and real-world situation. More importantly, this study provides a risk cause-and-effect diagram of the failure modes to help decision-makers quickly identify the critical failure modes. The effectiveness of the proposed model is demonstrated by applying it to a benchmark case in Taiwan.

■ TB-39

Tuesday, 10:30-12:00 - Q014

Multi-Project Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Mario Vanhoucke*
Chair: *Tom Servranckx*

1 - The RCMPSP: an evaluation of benchmark data sets and a decoupled scheduling approach
Rob Van Eynde, Mario Vanhoucke

The resource-constrained project scheduling problem (RCPSP) is a well-known problem in which a set of activities needs to be scheduled subject to precedence and resource constraints. The resource-constrained multi-project scheduling problem (RCMPSP) is an extension where a portfolio of projects needs to be scheduled. In recent years, more attention has been devoted to this problem and its extensions. Although more solution procedures are being developed, they are not necessarily tested on the same benchmark instances, impeding a standardised comparison. We compare the existing data sets and analyse their differences using summary measures from multi-project literature. Furthermore, we extend an existing generation procedure such that it can generate a wider variety of multi-project instances.

Previous literature has shown that algorithms which separate project and activity information provide a promising research avenue. In our study we extend the regular schedule generation schemes from single-project literature such that they decouple the project and activity selection decisions. A new set of priority rules is proposed for these schemes and their performance is compared with the existing regular schedule generation schemes. The computational experiments are executed on all available data sets in literature and the performance differences between these data sets is analysed.

2 - The impact of activity mode disruptions in multimode project planning
Jeroen Burgelman, Mario Vanhoucke

This abstract presents a general disruption system to simulate activity mode disruptions in a multimode resource-constrained project scheduling problem. A set of baseline schedules containing multiple alternative execution modes for each project activity is generated. We reconcile information regarding the preferred execution mode for activities in a multimode project scheduling context and the recovery approach adopted by the decision maker. The constructed set of baseline schedules at the project planning phase results in options to switch between the execution modes of activities during project execution. We assess the performance of the set of baseline schedules under several mode implementation disruptions. An effective heuristic algorithm is presented to construct the set of baseline schedules. Moreover, computational evidence on the impact of different activity mode disruptions during project execution is reported.

3 - Resource-constrained project scheduling with alternative subgraphs under uncertainty
Tom Servranckx, Mario Vanhoucke

In a complex and uncertain project environment, a baseline schedule provides an important point-of-reference for successful project completion. The resource-constrained project scheduling problem with alternative subgraphs (RCPSP-AS) allows to model alternative execution modes for subsets of activities or work packages in the project structure. This extension of the well-known RCPSP relaxes the assumption of a deterministic project structure in order to be able to better deal with the complex and uncertain project environment. The aim of the RCPSP-AS is to schedule the selected activities subject to technological and resource constraints such that the project makespan is minimized. In the presence of uncertainty, the alternatives in the project structure could also be used to create a set of back-up schedules in order to tackle unexpected disruptions in the project. At different decision moments during the project execution, these alternative schedules can then be switched to overcome disruptions. In this research, we present an approach to construct so-called similar and dissimilar sets of high-quality back-up schedules for instances of the RCPSP-AS. The degree of similarity of a set of schedules is determined by the number of included alternative schedules with similar selected alternatives in the project structure. Using a comprehensive simulation experiment, we investigate the ability of similar and dissimilar sets of schedules to tackle various uncertainty scenarios.

4 - Practical application of Reference Class Forecasting: identifying the drivers of similarity between projects
Wout Vandoorne, Mario Vanhoucke

Project managers usually tend to underestimate the cost and duration of projects. Reference Class Forecasting (RCF) is a technique which bypasses human judgment by forecasting new projects based on the outcomes of similar previous projects. However, in order to construct a relevant reference class of historical projects, it is necessary to identify the properties that will increase its accuracy. Moreover, a reference class should be broad enough to be meaningful but narrow enough to be similar.

This research contains data of 52 real-life projects and insights of 76 project managers across Belgium and Italy. First, the collected data is complemented with a qualitative study on the drivers of similarity between projects. Secondly, the corresponding findings result in the starting-point of a quantitative study in which both the relevance of the properties and the accuracy of possible reference classes are tested. Eventually, this research proposes an answer to the existing trade-off between the number of properties included in the reference class (which determines its similarity) and the number of historical projects that meet these properties (which determines how meaningful the reference class is).

■ TB-40

Tuesday, 10:30-12:00 - Q015

Transportation Using Autonomous Vehicles

Stream: Vehicle Routing and Logistics Optimization II
Invited session
Chair: *Ann Campbell*

1 - Spatial and temporal synchronization of truck platoons
Anirudh Kishore Bhoopalam, Niels Agatz, Rob Zuidwijk

Automated vehicle technology enables the formation of platoons in which virtually linked trucks drive closely behind one another. Platooning helps to reduce fuel consumption and emissions. In this study, we look at the planning of platoons of two trucks on networks and Euclidean space. To determine the platoons and the associated synchronized truck routes, we present an exact algorithm and several quick heuristics. In addition, we use, in particular, the Euclidean case to provide theoretical insights. We perform numerical experiments on different instances to study the impact of the maximum detour length and the waiting time on the total system-wide travel costs.

2 - Use of Autonomous Delivery Vehicles for Urban Deliveries
Ann Campbell

We will examine the idea of having deliveries made by an autonomous vehicle. The vehicle will still have a "driver". The driver will take the packages from the vehicle and deliver them to doors of the recipients on foot. With an autonomous vehicle, though, the driver will not have to find a parking spot for the vehicle before departing the vehicle to make the deliveries. The vehicle should be able to find its own parking spot or circulate until the driver is ready to be picked up and transported to its next location. This application of this new technology raises questions such as where the driver should be dropped off and, more importantly, what savings does this technology offer in terms of the completion time of the route? We will examine these questions in an urban environment, where the deliveries occur at the intersections of a grid. We can analytically derive the cost of the optimal solution. We will compare with more traditional approaches.

3 - Bi-criteria Network Path-finding for Shared-Ride Automated Vehicles: Considering Travel Time and Proximity to Demand
Michael Hyland

Shared-ride mobility services offered by transit agencies (e.g. demand-responsive transit) and private companies (e.g. Uber Pool, Lyft Line) have the potential to provide high-quality and affordable service to individual travelers, while simultaneously decreasing roadway congestion and vehicle emissions through higher vehicle occupancies. Shared-ride services face several challenges including behavioral issues associated with the unwillingness of travelers to share rides with strangers and operational issues associated with dynamically planning vehicle routes under considerable demand, travel time, and pickup time uncertainty. The current study focuses on improving operational efficiency via proposing a bi-criteria network path-finding approach for shared-ride vehicles that considers minimizing travel time and maximizing proximity to (expected) demand. Compared with assigning a vehicle to the shortest path between its current location and its next planned pickup or drop-off location, the bi-criteria approach should increase sharing opportunities and vehicle utilization and decrease unnecessary detours and operational costs. This study focuses on the case of fully-automated vehicles (AVs) that completely comply with non-shortest path directions. This study includes a mathematical program and solution algorithm for the bi-criteria shared-ride AV path-finding problem. Finally, the presentation will discuss extensions to the stochastic dynamic case and to the entire AV fleet.

4 - The efficient use of shared automated vehicles
Theresia van Essen, Jacopo Pierotti

The introduction of automated vehicles (AVs) on public roads will alter the current transportation system tremendously. Expectations are that AVs will transform vehicles from privately owned assets to an on-demand service. This transformation will also enhance the possibility of sharing trips, leading to shared AVs (SAVs). Such a scenario will result in a paradigm shift in conventional mobility: vehicles will be owned by transport companies and will be used on-demand. During this presentation, we will introduce two integer linear programming models to solve the a posteriori dial-a-ride problem with transfers (DARP-T), which assigns passengers to vehicles and routes while allowing ridesharing and transfers. Our models take into account all the aspects of the standard DARP-T, and in addition, convenient parking, service times, constraints on maximum route time-span, unserved requests, preferred arrival and departure times, and non-constant travel times. As objective function, we consider minimizing routing costs and maximizing quality of service. The developed models will be tested on benchmark instances by solving them with commercial solvers. The results will be used to validate the performance of forthcoming meta-heuristics which can be used in real-life.

■ TB-41

Tuesday, 10:30-12:00 - Q013

Uncertainty, delays and disruptions in railways

Stream: Public Transportation I
Invited session
Chair: Evelien van der Hurk

1 - An approximate dynamic programming approach to train trajectory optimization under uncertainty
Alessio Trivella, Pengling Wang, Francesco Corman

The train trajectory optimization problem consists in determining the speed profile of a train between two consecutive stations that minimizes energy consumption while respecting the scheduled arrival time, signaling constraints, and operational constraints such as speed limits and time windows. The problem is well-known in the literature and has so far been studied as a deterministic optimization problem in which driving controls take place in a fully known environment. In reality, train trajectory optimization is subject to stochastic factors that affect energy consumption and travel time. For example, the train resistance typically fluctuates significantly within the journey or among journeys on the same track due to external factors like wind and number of passengers. To account for this uncertainty, we formulate the problem as a Markov decision process (MDP) which is intractable due to its high-dimensional state space. We tackle this MDP by adapting an approximate dynamic programming method based on Monte Carlo simulation to learn a value function approximation. Computational experiments on real-life instances show that our driving policy outperforms deterministic policies and simpler heuristics by providing more efficient trade-offs between average energy saving and travel time.

2 - An Efficient Heuristic for the Rolling Stock Rescheduling Problem
Rowan Hoogervorst, Twan Dollevoet, Gabor Maroti, Dennis Huisman

We present a heuristic for the Rolling Stock Rescheduling Problem (RSRP). Rolling stock rescheduling is performed when a disruption leads to changes in the timetable. In the RSRP, we then assign train units, which can be of different types, to the trips in this new timetable. The objective is to assign the rolling stock in such a way that both passenger comfort and operational performance are taken into account. We propose a variable neighborhood search heuristic to solve the RSRP. Our main search neighborhood relies on fixing the assignment for all-but-one rolling stock types and then iteratively improves the assignment for the remaining type. Moreover, we additionally perform a perturbation step to improve the assignment across the different train unit types. We benchmark our heuristic on instances of Netherlands Railways (NS). The results show that our heuristic is able to find high-quality solutions in a reasonable amount of time. In particular, this allows rolling stock dispatchers to use our heuristic in real-time rescheduling.

3 - Decentralized Rolling Stock and Crew Dispatching Strategies for Extreme Disruptions
Rolf Van Lieshout, Paul Bouman, Marjan van den Akker, Dennis Huisman

About once or twice a year, extreme disruptions such as power outages or severe weather conditions cause the Dutch railway network to get into a state of out-of-control, meaning that dispatchers lose the overview over the network and therefore decide to terminate all railway services in the disrupted region. In this talk, we discuss how decentralized dispatching strategies can help to quickly restore traffic in these situations. We propose a simple decentralized rolling stock dispatching algorithm and prove that it maximizes rolling stock utilization in the long run. Furthermore, we propose and compare decentralized crew dispatching algorithms that use different coordination mechanisms in order to quantify the value of coordination. All in all, our results illustrate the potential of decentralized dispatching strategies to establish a decent service level when centralized dispatching is no longer viable.

4 - Train Delay Prediction in the Netherlands through Neural Networks
Evelien van der Hurk, Joergen Haahr, Erik Hellsten

Accurate predictions of future train event times are of great value to passenger service information systems, to dispatchers who may be able to use it to anticipate conflicts, and to many types of real-time capacity rescheduling models such as crew and rolling stock rescheduling. This work investigates to what extend low-maintenance out-of-the-box machine learning models can provide accurate predictions of future delay and delay development for trains in dense-traffic networks with heterogeneous train demand based on historical data for the ultra-short period of 20 minutes ahead. Results indicate that indeed such models can outperform a constant prediction model, especially when one values the forecast of large delay changes. The presentation will share information on this RAS first prize winning model as well as further development.

■ TB-42

Tuesday, 10:30-12:00 - Q113

Intelligent and Sustainable Solutions for Transportation and City Logistics I

Stream: Transportation
Invited session
Chair: *Michele Ottomanelli*
Chair: *Leonardo Caggiani*

1 - Air Passenger Demand Forecasting using Deep learning methods
Nahid Jafari

Demand for air travel is essentially driven by economic and tourism activities. The economic recessions decreases demand for leisure and business travel, consequently, demand for air transport which is the most important transportation mode in the United States. As the economy recovers from economic downturns, the aviation industry will continue to grow over the long run. Air transport demand forecasting is receiving increasing attention, especially because of intrinsic difficulties and practical applications. The forecast of the air passenger demand over time can be analyzed as time series forecasting in which it has a complex behavior due to their irregularity, high volatility and seasonality. Among quantitative forecasting approaches, econometric, statistical and artificial intelligence approaches are well-known. In this study, we examine various deep learning methods to predict the air passenger demand of the U.S. domestic airlines. Deep neural networks, a multiple layer perception (MLP) with multiple hidden layers, can learn more complicated function of the input. We frame the problem where, given the air passenger demand for prior years, we forecast the passenger demand (aggregate and disaggregate) for a short term. We implement the models with Keras, the Python deep learning library.

2 - Energy-saving applications in the case of rolling stock failures
Marilisa Botte, Luca D'Acierno

Current sustainable policies, adopted by most of the world's governments, have shown the necessity to promote the use of public transportation systems which provide lower external costs (such as congestion, accidents, air and noise pollution) compared to road transportation systems. In this context, the rail and metro systems allow to achieve further two objectives: the increase in efficiency (i.e. operational costs for real/potential carried passengers) and the delocalization of energy production centres (i.e. large industrial plants out of population centres). The above-mentioned positive aspects may be further increased by applying suitable energy-saving and energy-recovery strategies, generally based on the on the adoption of suitable driving profiles and/or installation of on-board/lineside storage devices. In this context, our proposal is based on the investigation of the effects of rolling-stock failures (for breakdowns, maintenance or under-sized fleet) on the effectiveness of energy-saving/energy-recovery measures within a multi-objective framework which combines the reduction in energy consumption with a passenger-oriented perspective. A regional rail line in the south of Italy has been analysed as case-study in order to show the feasibility of the proposed approach.

3 - Solving and applying large queueing models for public transit networks and freight railway transportation systems
Esteve Codina, Francisca Rosell

Queueing models in transport networks are a key component in various models, such as assignment models for both public transport and traffic networks, rail networks, etc. and they are a fundamental element on which the representation of congestion and its effects often relies. The present work deals in detail with the application to assignment models of passengers to public transport lines and rail freight transport networks. In these strategic models, simplified queueing models are generally adopted which provide delays as response to mean steady-state flow. In the two mentioned cases of assignment models the line choice is made by choosing hyper-paths that reflect an attractive set of lines. In the literature, several queueing models of the bulk service type have been suggested, but in the case of a route choice based on strategies, no theoretical model has been yet validated. Another question to be taken into account is that, in reality, it would be more appropriate to use queueing models with interruption of service in a transient state. In this paper, a novel method is developed to solve queueing models in bus stops for multiple lines and in railway freight terminals based on the efficient resolution of the corresponding continuous time Markov chain models of large dimensions and in the determination of solutions for the transient state. The application of these queueing models is shown in various transit assignment and freight railway test networks

■ TB-43

Tuesday, 10:30-12:00 - Q114

Facility Location in Humanitarian Logistics

Stream: Location Analysis and Optimization
Invited session
Chair: *Glaydston Ribeiro*

1 - Logistic network design for search and rescue services
Mehdi Amiri-Aref, Atefe Baghaian, Mohammad Mehdi Lotfi

This paper investigates the challenge faced by search and rescue (SAR) teams in casualty management operations. After a disaster hits, practitioners must decide on the location of temporary emergency centers to serve the affected sites and the capacity and routing of SAR teams. Relevant studies emphasized the impact of including uncertainty and dynamicity when designing a post-disaster humanitarian logistic network. These decisions are made by anticipating the possible realizations on the number of casualties in affected sites due to the uncertainty inherent in severity and effect of a disaster. Therefore, we aim to develop a mixed integer-programming model to locate, dispatch and deploy SAR teams in such an uncertain environment through a stochastic multi-period multi-objective location-routing problem for SAR operations after natural and man-made disasters. The uncertainty considered in the model is formulated in the form of several scenarios incorporated in the model, as the number of injured people changes over time. To consider ethical and accessibility aspects, the model minimizes the following two objectives; the total expected number of unsaved people and the total expected travel time of SAR teams. We apply a heuristic solution algorithm with a case study data of SAR operations in Texas.

Finally, useful managerial insights are presented by conducting some numerical analyses.

2 - Location and Capacity Optimization under Resource Shortages for Emergency Response
Ozgur Araz, Adrian Ramirez Nafarrate, John Fowler

Emergency response preparedness requires strategic and operational planning. In this paper, we present a flexible algorithm to evaluate tradeoffs in resource scarce situations with response time pressure. We analyze the location-allocation problem with capacity and time constraints, and the objective of minimizing the service time for individuals in an affected area. Due to the complexity to solve the problem for large scale scenarios, the presented algorithm relaxes capacity and time constraints, simultaneously, and present flexibility to assess tradeoffs. A modified NSGA-II algorithm is used with a penalty function to leverage resources. We analyze how values of the penalty parameters interact with the number of open sites in defining an efficient resource allocation strategy. Therefore, decision makers can expand their choices to design an emergency response network with their preferences taken into consideration.

3 - An approximation algorithm for Reliable Facility Location Problem
Megha Sharma, Sumanta Basu

Uncapacitated facility location problems (UFLP) have been extensively studied in the literature. The classic UFLP assumes that once a facility has been located, it will be available to meet customers' demand through out the planning horizon. However, this assumption does not hold in many real life situations, as facilities become non-operational due to natural calamities, labour union strikes, and terror attacks. Therefore, a more realistic model of the problem, called the Uncapacitated Reliable Facility Location Problem (URFLP) accounts for facility failures by associating a probability of failure with each facility and attempts to minimize the expected cost of setting up the facilities and meeting the customers' demand.

Several researchers have studied the URFLP and have presented different model formulations. As the URFLP is an NP-hard problem, solution approaches proposed for it, include exact methods, approximation algorithms and heuristics solution methods. Currently, the best-known approximation algorithm for URFLP outputs a solution that is guaranteed to cost not more than 4-times the optimal cost of the URFLP. In this paper, we present a linear programming relaxation based approximation algorithm that outputs a solution, which is guaranteed to cost less than 3 times the optimal cost of the URFLP.

4 - A Pareto analysis for the mutiobjective emergency vehicle base location problem
Glaydston Ribeiro, Thayse Ferrari, Marcus Camara

The Multiobjective Emergency Vehicle Base Location Problem (MEVBLP) involves several criteria that need to be analyzed, such as demand to be met, costs for the base location, the response time to emergency calls, among other relevant aspects, to find the best places for the bases of the emergency vehicles. In multiobjective approaches, there is no single solution that meets all objectives simultaneously due to the tradeoff present in this these problems. However, find the set of efficient solutions, or Optimal Pareto, for large real multiobjective problems is a complex task which requires high computational times. This paper aims to analyze the tradeoff existing in MEVBLP taking into account real instances of the Rio de Janeiro City - Brazil. We implemented an exact method for the MEVBLP where the results for small instances are used for tuning of a Multiobjective Evolutionary Algorithm (NSGA-II). The computational tests use data obtained with the registers of pre-hospital care under the responsibility of the Emergency Relief Group of the Military Fire Department of the State of Rio de Janeiro. This database includes 482,000 records with the historical series of appointments for the years 2013 - 2015. Our results show that NSGA-II find good solutions for the problem.

■ TB-44

Tuesday, 10:30-12:00 - Q115

AHP Theory, Tools and Methods

Stream: Analytic Hierarchy Process
Invited session
Chair: *Alessio Ishizaka*

1 - Consensual Group-AHPSort
Luis Martinez, Álvaro Labella, Alessio Ishizaka

Group-AHPSort is a Multi-criteria group decision making (MCGDM) method for dealing with sorting problems within group schemes. These problems consider information from several experts with their own attitudes and knowledge to reach a solution which may imply the inherent apparition of conflicts among them, which might lead to deadlocks that make hard or even impossible to achieve a decision. To smooth such situations consensus reaching processes (CRPs) have been included in the resolution process of group decision problems facilitating the negotiation to achieve agreed solutions by the group. Most of CRPs applied to MCGDM has been focused on decision problems for ranking and selection of alternatives but not on sorting decision problems. Due to the importance of sorting problems in Multi-criteria decision making (MCDM) and hence in MCGDM this contribution focuses on the development of a CRP for the well-known MCGDM-sorting method, Group-AHPSort, which so far does not take into account consensus measures and, as consequence, disagreement among experts who participate in the classification process. The aim of this CRP in Group-AHPSort is avoid misclassifications that might be produced by the disagreement among the group of experts participating in a MCGDM problem.

2 - ANPSort for sorting researcher
Alessio Ishizaka

Six problem formulations exist in multi-criteria decision analysis (MCDA): choice, sorting, ranking, description, elimination and design problems. MCDA methods are generally developed for choice or ranking problems. Recently, several methods have been adapted for sorting problems. However, they all assume that the criteria are independent, which is often not the case practically in real life. Therefore, this paper proposes a new sorting technique ANPSort, which can handle problems and challenges with interdependent criteria. Moreover, another practical limitation of ANP is that a high number of alternatives implies a large number of comparisons. In comparison, our proposed ANPSort requires far less comparisons than ANP, which facilitates decision making within large scale problems. It further allows a structured, transparent and consistent evaluation integrating qualitative and quantitative criteria. In this paper, we contextualize and problematize this challenge and contribute through the lens of a practical case study in an higher education academic setup specifically concentrating on a topical area of 'researcher classification', to illustrate our concept and approach.

3 - Redesigning e-Banking services: Social and Environmental Challenges towards Sustainable Development.
George Paltayian, Andreas Georgiou, Katerina Gotzamani, Andreas Andronikidis, Konstantina Kamvysi

In response to new market challenges there is a need for re-designing e-banking services introducing economic, social and environmental sustainability considerations along with quality parameters. Hence, the purpose of this paper is to develop a three-phased consolidated QFD (Quality Function Deployment) methodological framework encompassing AHP, to align e-banking platform design decisions with factors influencing consumer behavior towards e-banking services with economic, social and environmental sustainability criteria. Toward this direction an extension of QFD method based on Decision Analysis and Multicriteria methods is proposed. The ultimate aim is to promote electronic banking as a means for economic advancement, social inclusion and environmental protection and not solely as a transaction service.

■ TB-45

Tuesday, 10:30-12:00 - Q117

Modeling transport decisions with multiple stakeholders

Stream: Transportation and Logistics
Invited session
Chair: Virginie Lurkin

1 - A bilevel approach for the emergency management of offsite hazardous wastes considering multi-quality coverages
Ginger Y. Ke, Jiahong Zhao

Hazardous wastes pose increasing threats to people and environment during the processes of offsite collection, storage, treatment, and disposal. A novel game theoretic model, including two levels, is developed for the corresponding optimization of emergency logistics, where the upper level indicates the location and capacity problem for the regulator, and the lower level reflects the allocation problem for the emergency commander. Different from other works in the literature, we focus on the issue of multi-quality coverages (full and partial coverages) in the optimization of facility location and allocation. To be specific, the regulator decides the location plan and the corresponding capacity of storing emergency groups for multiple types of hazardous materials, so to minimizes the total potential environmental risk posed by incident sites; while the commander minimizes the total costs to provide an efficient allocation policy. To solve the bi-level programming model, two solution techniques, namely a KKT condition approach and a heuristic model, are designed and compared. The proposed model and solution techniques are then applied to a hypothetical case and a real-world case to demonstrate the workability and provide managerial insights.

2 - A demand-based optimization approach to study oligopolistic markets
Virginie Lurkin, Stefano Bortolomiol, Michel Bierlaire

Oligopolistic competition occurs when a small number of operators compete for the same pool of customers. This is often the case in transportation, due to reasons such as external regulations, limited capacity of the infrastructure and difficulty in entering a well-established market. In our work, we propose a demand-based optimization approach to study oligopolistic markets. The framework takes into account interactions between demand and supply as well as competition among suppliers. In particular, the preferences of the customers are modelled at a disaggregate level according to random utility theory, while competition is modelled explicitly as a multi-leader-follower game in which all suppliers (leaders) simultaneously optimize their decisions based on their knowledge of the customers (followers). A fixed-point optimization model to find equilibrium solutions of such games is presented which can incorporate both nonlinear and linearized customer choices probabilities.

3 - A Bi-Objective Model for Design and Analysis of Sustainable Intermodal Transportation Systems: A Case Study of Turkey
Giray Resat

This study presents a mixed-integer linear optimization model to analyse the intermodal transportation systems in Turkish transportation industry. The problem is designed to introduce the modelling approach, data analysis from real-life cases and outline important characteristics of mathematical programming problem to minimize total transportation cost and carbon dioxide emissions by using two different exact solution methods to find out the optimal solutions. The novel approach of this study is getting faster and more sustainable Pareto solutions for decision makers by using new developed solution methodology for bi-objective mixed-integer linear problems in the real-life cases.

4 - Multi-objective multimodal routing: A metaheuristic solution approach
David Wolfinger, Karl Doerner

We address a planning problem faced by logistics service providers who transport freight over long distances. Given a set of transportation requests, where the origin and the destination of each request are located far apart from each other, a logistics service provider must find feasible vehicle routes to fulfill those requests at minimum cost. When transporting freight over long distances, multimodal transportation provides a viable alternative to traditional unimodal road transportation. We consider three modes of transportation: road, water and rail. When transporting a request in a multimodal fashion the problem corresponds to a pickup and delivery problem with transshipments. In addition, we allow the load of a request to be split among several vehicle trips. The objective is to find a set of feasible vehicle routes that serves all requests, such that the sum of travel costs and transshipment costs is minimized. Each transshipment, however, makes it more complicated for practitioners. That is, the number of logistics operations and administrative tasks increases with each transshipment, as well as both the vehicle routes and the product flows become more complex. Thus, we consider an additional objective in order to generate a range of solutions with varying practicability: minimize the average number of transshipments per request. We propose a solution method for the bi-objective problem based on adaptive large neighborhood search and present preliminary results.

■ TB-46

Tuesday, 10:30-12:00 - L243

Decision Making under Vagueness

Stream: Decision Making under Imprecise and Vague Information
Invited session
Chair: Davide Petturiti
Chair: Maria Letizia Guerra

1 - A Further Contribution of Mixed Integer Programming for the Correction of Incoherent Assessments
Andrea Capotorti

Mixed integer programming (MIP) is showing an even greater attitude to deal with check and correction of coherence of partial probability assessments. In fact, it was firstly, and successfully, adopted to check coherence of unconditional partial probability assessments. Later, MIP has been used inside a general procedure to correct incoherent assessments through minimization of L1 distance. Such procedure, easily interpreted by non-expert users, has been integrated in belief merging (both supervised or unsupervised) and in revision of different partial assessments stemming from inconsistent sources of information. From this, its adoption found significance in the so-called statistical matching problem, both in its original formulation and in its extension to misclassification scheme. It is now possible to show how a shrewd use of constraints and of slack variables permit to steer the correction of incoherent assessments towards aimed directions, like, e.g., the possibility only to increase or decrease specific values, or that to maintain fixed a specific subset of the initial assessments. Since such procedures are based on L1 distance minimization, they all obey the basic principle of minimal change in a numerical uncertainty setting. With a further tricky use of binary variables, it is also possible to minimize the number of valuations, in line with one basic principle of optimal corrective explanation for decision makers.

2 - Decisions under Partial Knowledge in a Fuzzy Environment
Barbara Vantaggi, Giulianella Coletti

In decision processes under partial, imprecise or vague information it is necessary to elaborate a knowledge acquisition model able to encode statistics and fuzziness and to upgrade knowledge trough inferential rules generalizing the Bayesian methods .

We refer to an interpretation of membership function of a fuzzy set, in terms of either a coherent conditional probability or a coherent conditional possibility, regarded as function of the conditioning event. As a consequence the notions of fuzzy event (due to Zadeh) and fuzzy partition (due to Ruspini) have been reinterpreted. A comparison between the two methods is provided.

Our first aim is to give a syntactical motivation for choosing some particular t-norms and t-conorms (such as the minimum and maximum), instead of others (such as Lukasiewicz t-norm and t-conorm). Another aim is to give a selection model procedure. The proposed method is essentially based on aggregated likelihood functions, and on the disintegrability condition in order to avoid unpleasant situations, where the conditional priors coincide with the membership functions associated to the elements of the fuzzy partition. In order to select one or more elements of the partition we use a fuzzy Bayes factor. An application of the proposed method will be shown.

3 - Fuzzy-Transform Smoothing for Volatility Forecasting

Maria Letizia Guerra, Laerte Sorini, Luciano Stefanini

New smoothing methodologies based on quantile and expectile defined as L1-norm and L2-norm Fuzzy transforms have been recently introduced in International Journal of Approximate Reasoning; therein, just to explore some preliminary facts, we briefly analyze three financial time series volatility on annual basis showing a direct relationship between Mean Average Variance (MAV) induced by our methods and historical volatility, carefully taking under consideration that volatility is expressed as a percentage based on intra-day returns, whereas MAV takes into account intra-day price variations not in percentage basis. An effective modelling of volatility is one of the most studied field in finance research and we think that Fuzzy- transform can contribute through a robust theoretical model with interesting properties also for practitioners. In the present contribution we investigate deeper possible connections of fuzzy-valued smoothing with volatility in markets that is commonly measured as a standard deviation in a probabilistic scenario; we show that, by adopting a fuzzy-valued approximation, we can apply fuzzy logic and possibility theory to formulate or revise volatility-

■ TB-47

Tuesday, 10:30-12:00 - L247

Modelling behaviour

Stream: Behavioural OR
Invited session
Chair: Alexander Baumeister

1 - Group decision making with affective characteristics

Si Liu, David Rios

So far many researchers have proceeded the decision making methods by explaining them for a single agent. Although the observations of one agent in a process do not mean to separate the model, there are crucial problems in which it maybe preferable to use group models which need focus on joint predictions and decisions among a group of agents. Moreover, considering the conclusion that emotions powerfully and predictably influence the way of agent making decision, we present a two-stage group decision-making model in the context of agents' affective characteristics. Agents based on various personalities and objectives have been clustered into several subgroups. Different decision-making mechanisms applied in a clustered subgroup which is treated as a unity globally, and among subgroups according to the cooperation or competition. We conduct several experiments to compare different cluster methods and parameterized setting, and in the end prove the group decision-making process feasible and reasonable.

2 - Evaluating pharmaceutical external reference pricing regulation in the EU: A hybrid resource/agent modelling approach

Rossen Kazakov, Susan Howick, Alec Morton

External reference pricing (ERP) regulation and its effect on drug access, affordability and availability in the EU has not previously been explored by dynamic simulation methods except through a single study using a discrete event simulation approach which paid limited attention to the adaptive behaviour of market actors.The authors have developed a hybrid agent based and system dynamics simulation model to explore the above mentioned effects of the ERP regulation including its impact on agents' decision making. The building of the hybrid simulation model was supported by the use of Resource Agent Maps, a novel qualitative modelling technique designed to analyse the interactive behaviour of agents and resources in a complex adaptive systems environment. The development of the qualitative maps and quantitative simulation model ensured theoretical and methodological consistency and helped to support confidence in the simulation model building process. The simulation results demonstrate that the intended effect of the external reference pricing to decrease medicine prices results in the counter effect of maintaining higher prices for longer periods of time, market entry delays and withdrawal of medicinal products from the market.

3 - The assignment problem in human resource project management - case of innovative and innovation projects

Helena Gaspars-Wieloch

The assignment problem (AP) is a discrete and combinatorial problem where agents are assigned to perform tasks in order to maximize the total efficiency (minimize the total cost/time). AP is also known as the maximum-weight matching and is a part of human resource project management. The AP optimization model contains binary variables. In the case of deterministic parameters describing the agent-task performance AP can be easily formulated and solved, but this situation is characteristic of standard, well-known projects. When considering new projects, the parameters estimation becomes more complex. It depends on the similarity of those projects to previous projects already accomplished. If there are some similarities one can set possible scenarios and even probabilities related to them, but if there are very few common features the use of probabilities seems to be unjustified. In the presentation we investigate the case of innovative and innovation projects. They are so original that historical data can be used to a limited extent. Hence, we do not recommend the probability calculus application in such circumstances. We suggest an algorithm based on scenario planning and the optimism coefficient which allows describing the decision maker's nature (i.e. his/her attitude towards risk). The procedure is designed for one-shot decisions and pure strategies. This research is supported by the National Science Center, Poland [grant number 2014/15/D/HS4/00771].

4 - Behavioural impact on the valuation of flexibility in project management

Alexander Baumeister, Markus Ilg

Real option valuation dealing with the assessment of flexibility is widely discussed in literature and used for project management decisions in practice. However, behavioural deformations of decision makers such as over-optimism or the impact of imperfect, noisy information could induce an overvaluation of project flexibilities. Hence, both effects have to be considered in project management by adjusting the real option values of projects. Therefore, we outline key elements of naturalistic decision making theory that should be included in the valuation of a project's flexibility, develop a model for project valuation in a multi-period setting, illustrate the procedure using a simulation case study with abandonment options in IT project management and recommend how to integrate behavioural deformations in real life decisions.

■ TB-48

Tuesday, 10:30-12:00 - L248

Energy Production and Distribution I

Stream: Applications of Dynamical Models
Invited session
Chair: Miguel Muñoz Ortiz

1 - The Interaction between Flexible Generators and Temporal Aspects of Electricity and Reserve Markets
Mathias Hermans

To cope with the large scale introduction of intermittent renewable energy sources (RES), short reaction times of dispatchable generating units are crucial. This reaction time is both governed by the lead times on the start-up decisions, the frequency of RES forecast updates and the planning or market clearing frequency. The start-up lead times are limited by the operator's tolerance for life time reductions of the asset, which should be reflected in short-term scheduling models. In light of these challenges, a unit commitment model that accounts for the start-up lead times in a rolling horizon approach is presented. The model allows reflecting multiple start-up flexibility capabilities and aims to capture the scheduling decisions of the day-ahead and intraday electricity markets, the operating reserve market and the final activation of the contracted operating reserves. The RES uncertainty is presented through realistic wind power forecast updates generated by a data-driven tool. Leveraging this model, we investigate the interaction between the frequency of wind power forecast updates and corresponding planning adjustments, cost-optimal reserve requirements and CCGT start-up decisions in the presence of varying shares of RES. Results show that cost-optimal reserve sizing is a function of the planning frequency, and that depending on the inherent flexibility of the test system, short start-up capabilities regularly benefit the electricity generation system.

2 - Predicting EV Departure Time For Smart Charging
Oliver Frendo, Nadine Gaertner

Smart charging is motivated by insufficient electrical infrastructure including a lack of charging stations as well as undersized power lines. Currently, smart charging in real-time relies on incomplete information due to unpredictable user behaviour. This includes information such as arrival and departure time. Using inaccurate arrival and departure time leads to poor prioritization of charging processes thus motivating the need for reliable estimations. Related work on smart charging often uses a prioritization mechanism to create and adapt charging schedules. During real-time adjustment of a charging process its priority can be affected by a combination of factors such as departure time and state of charge (SoC). We use a heuristic for creating charging schedules and a priority function as described above. Currently, priority functions make use of static information. We propose improving the accuracy of the priority function by integrating predictions for data such as departure time. In this work, we consider regression methods for estimating electric vehicle (EV) departure time based on historical data. We then analyze and compare the effects on the quality of resulting schedules. Experimental results show that improving the accuracy of the priority function improves the quality of charging schedules by using the available infrastructure capacity more fully over time.

3 - Business Cases for Remote Micro-Grids and Off-Grids with Hydrogen-Based Technologies.
Miguel Muñoz Ortiz, Vibeke Nørstebø, Adrian Werner, Kyrre Sundseth

Many areas in the world are partly or totally isolated and sometimes energy supply is challenging. At the same time, a shift to renewable energy production is demanded in order to fight climate change. However, renewable energy production is often unstable and unpredictable and therefore there is a need to develop energy solutions that can provide a secure energy supply to remote areas. REMOTE is an EU project which aims to demonstrate the technical and economic feasibility of two fuel cells-based H2 energy storage solutions (integrated P2P system; non-integrated P2G+G2P system), deployed in 4 DEMOs, based on renewables, in isolated micro-grid or off grid remote areas. One important task of the project is to formulate of the business cases for the four DEMOs Then, define the value chain and the business model. In this presentation the DEMO cases are presented, including units of analysis, time span, assumptions, cash flows, actors, technologies needed. Then, the economic model is defined and refined using the optimisation tool HyOpt (based on Mosel language), where the key aspect to be investigated is a method for matching demand and production and integration among new and old/existing investments. Finally, the business cases are demonstrated, showing which is the value chain and how the DEMO will become a clear example of business in the domain of energy storage in isolated micro grids or off grids.

■ TB-49

Tuesday, 10:30-12:00 - L249

Software tools for optimization modeling and solving

Stream: Software for Optimization
Invited session
Chair: Ansuman Swain

1 - JuMP and MathOptInterface: An optimization framework extensible by design
Benoît Legat, Joaquim Dias Garcia, Oscar Dowson, Miles Lubin

This talk presents the optimization interface MathOptInterface (MOI), an abstraction layer that replaces the previous solver abstraction in JuMP. While the previous interface had 3 fixed problem format: Linear/Quadratic, Conic and Nonlinear, the MOI interface is generic. An optimization problem is described by an objective and a list of constraints written in the form function-in-set. Standard types of functions are defined in MOI but new ones can be defined independently. This allows algorithms that can exploit novel problem structure to extend MOI and enable the user to model the custom constraint type in JuMP. In addition to this ability to encode custom constraint types, while optional, JuMP macros can be extended to provide a more convenient syntax for creating them.

The rich expressivity of the interface renders the interface challenging to implement completely for a solver. For these reasons, MOI is equipped with an automatic bridging mechanism. A bridge describes a transformation of a constraint into an equivalent form. If a constraint type is not supported, appropriate transformations will automatically be selected using an algorithm derived from Bellman-Ford. Thanks to bridges, a solver should only support the constraint types that exhibits a structure that is actually exploited by the solver while the user interface is enhanced with more modelling tools.

This is illustrated by the extension of JuMP to polynomials variables and Sum-of-Squares constraints.

2 - Update on Functions in AMPL
David M. Gay

This talk will provide an update on a project to augment the AMPL modeling language with functions declared in AMPL. AMPL has long allowed using functions from shared libraries, written in other languages. Functions directly expressed in AMPL should make some forms of modeling easier. In particular, providing callbacks to solvers should be easier with functions expressed directly in AMPL.

3 - Benchmarking Optimization Software- a (Hi)Story
Hans Mittelmann

For more then twenty years we have been providing information on optimization software. This includes in particular performance evaluations over a wide range of problems and for both commercial and noncommercial software. Of the commercial products mainly CPLEX, Gurobi, and XPRESS are benchmarked on our own problem selections or instance libraries when available. This effort informs the public about the state-of-the-art and pushes the developers to improve their codes. While this went smoothly for many years, in late 2018 an event changed the situation substantially. The development will be chronicled and in addition to the presented history, a story will be told about the recent episode and how it affects the future.

4 - A visualization tool for AMPL using MDDB features
Ansuman Swain, Gautam Mitra, Christian Valente

Optimization based decision support systems (DSS) and business intelligence (BI) systems are usually constructed using algebraic (optimization) modelling languages (AMLs). In the earlier generation of software systems such DSS/BI applications were created using external connectivity with database management systems (DBMS). In order to enable AMPL users to create DSS/BI applications we have developed a framework for AMPL in the following way. This framework can take a generic decision model created in AMPL and map the entities of the model to an MDDB. This MDDB representation, in turn, leads to two useful features. First it provides access to all the features of online analytic processing (OLAP). Second many visualization features can be used for the target applications. Our generic approach has the advantage that DSS/BI applications for multiple domains can be created easily by analysts who are experts in their own specialized application areas.

■ TB-50

Tuesday, 10:30-12:00 - Mason Hayes & Curran

Methodological and practical contributions of Soft OR/PSMs to Policy Making - I

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: Ine Steenmans

1 - Countering stereotypes: Including people in complex technology policymaking
Kruakae Pothong

The complexity of emerging technologies, such as the IoT, distributed ledgers and AI, makes it easy for people to be left behind, excluded in development of these technologies and policies shaping them. Science and Technology policies are known for their reliance on objective evidence, often excluding subjective evidence. Many people, already disconnected from politics, are resigned to this condition despite their requirements for aspects of technologies and the way technologies are used to change. Addressing this disconnection, this paper examines approaches to engage and include people in complex technology policy development. Based on deliberative theory, this paper explores scenarios in which people can equally, respectfully exchange values and preferences, understand their differences and collectively work out common grounds about how emerging technologies should work. The paper reports on drama and simulation based techniques, successfully used to enable people to draw on their experiences, as resources, deliberate on and make collective decisions regarding aspects of emerging technologies that affect their lives. The value of combining these techniques and deliberation lies in the resulting authentic problem definitions and approaches to address them, accounting for the diverse thoughts, capabilities, needs, demands of emerging technology users.

2 - How to design alternatives?
Alexis Tsoukias, Alberto Colorni

Alternatives are an essential primitive for any decision model, but are never "given" as such, but rather constructed through an interaction between the client and the analyst. We suggest a general framework on how to model this process and how to help conducting the alternatives construction activity. We use policy design examples to support the presentation.

3 - How to support policy decisions by combining public and private interests. The resuse of abandoned cultural heritage in Northern Italy.
Rossella Moioli, Stefano Capolongo, Leopoldo Sdino, Marta DellOvo, Alessandra Oppio

Built cultural heritage (BCH) preservation has to be based on rigorous methodological frameworks able to find a balance among protection instances, economic development and urban quality. The research is focused on the definition of decision aiding process for the reuse of an abandoned healthcare facility with several historic buildings. Public and private different needs have been taken into consideration, since both play an important role for the development of the analysed area and for definition of urban regeneration policies. Given the complexity of this issue, the evaluation process has been structured by combining different methodologies to support the policy cycle: i) the Stakeholder Analysis, that has allowed to identify actors engaged and to prioritize their needs (Social sustainability), ii) the Nara Grid for the values elicitation of the BCH (Cultural and environmental sustainability) and the subsequent definition of different sustainable scenarios; iii) Discounted Cash Flow Analysis (Economic sustainability). Four alternatives, in addition to the business as usual scenario, have been evaluated with the support of a Multicriteria Analysis aimed at defining the most balanced between heritage significance retention and urban regeneration. This work contributes to the literature on soft OR by exploring the interactions among different stakeholders and addresses policy instances by providing a transparent methodology based on the value elicitation.

4 - Soft OR for policy design - trends and emerging practices
Ine Steenmans

Decision aiding methods and processes have a long history of development for the spheres of public policy analysis and design. The prominence of soft operational research methods as a set of analytic tools within these spheres has waxed and waned since their initial development in the 1970s. Recent needs-centric, design-driven trends in the field of policy analytics appear, however, to be driving a period of revived, adaptive experimentation with those methods.

This paper traces the historical evolution of soft OR for policy, as well as highlights its emergent design science influenced formats. It finishes with grounded speculation on its future forms. Its focus is on UK practices, though observations on similarities and differences with experiences in other international public administrations will be made. Data collection comprises interviews with government analysts and active participant observation in systems mapping workshops (in which soft OR methods were blended with design techniques) with the UK Policy Lab. Analysis used a critical realist evaluation of longitudinal influences in the analytic paradigms used in policy design. Finally, the paper closes with reflection on the activities that the UK's Operational Research activity could engage in to maximise collective learning in this period of experimentation.

■ TB-51

Tuesday, 10:30-12:00 - William Fry

Optimal Control Applications 2

Stream: Optimal Control Theory and Applications
Invited session
Chair: Gustav Feichtinger

1 - Scientific Production vs. Obsolescence of Knowledge over the Life Cycle
Andreas Novak, Gustav Feichtinger

According to Way et al. (2017) four different research patterns can be observed during the career of a scientist. This phenomenon can be dealt with either in an only descriptive way, but in the literature also normative approaches can be found (see, e.g. a recent paper by Feichtinger, Grass and Kort, 2019). In our model we concentrate on the obsolescence of knowledge and follow the approach of McDowell (1982), but we correct a mis-specification of the production function to human capital and use the original function proposed by Ben-Porath (1967). An optimal control model is presented and the results are compared to other results found in the literature.

Ben-Porath (1967): The Production of Human Capital and the Life Cycle of Earnings, J.o. Political Economy, 75, pp.352-365.

Feichtinger et al. (2019): Optimal Scientific Production over the Life Cycle.

McDowell, J.M. (1982): Obsolescence of Knowledge and Career Publication Profiles: Some Evidence of Differences among Fields in Costs of Interrupted Carrers . The American Economic Review 72, pp.752-768.

Way et al. (2017): The Misleading Narrative of the Canonical Faculty Productivity Trajectory. Proceedings of the National Academy of Sciences 114.

2 - Infinite Horizon Control Problems – Duality – Fourier-Laguerre Analysis – Turnpike Properties

Sabine Pickenhain

We consider a class of infinite horizon variational and control problems arising from economics. The problem setting implies weighted Sobolev spaces as the state spaces. For this class of problems we use a duality concept of convex analysis to find sufficient optimality conditions. We develop a Fourier-Laguerre method to solve the dual problem in an Hilbert space setting and discuss turnpike properties of the solution.

3 - Optimal Coastal Fishing of Two Competing Species

Thorsten Upmann, Dieter Grass, Hannes Uecker

In many spatial resource models it is assumed that an agent is able to harvest the resource over the complete spatial domain. However, agents frequently only have access to a resource at particular locations at which a moving biomass, such as fish or game, may be caught or hunted. Here we analyse an infinite time horizon optimal control problem with boundary harvesting for two species described by a system of parabolic PDEs as state dynamics. We formally derive the associated canonical system, consisting of a forward–backward diffusion system with boundary controls, and numerically compute the canonical steady states and the optimal time dependent paths, and their dependence on parameters. Specifically we contrast different forms of taxation and evaluate the resulting policy implications. The well known Skiba phenomenon for ODE optimal control models, where two optimal solutions exist for the same initial states (distribution) also occurs in this spatial model. Under the assumption of homogeneous initial distributions we can numerically compute the according Skiba curve and analyse the shift of this curve within the different taxation regimes. Another phenomenon that has occasionally be observed in ODE models but has not been described for spatially distributed models is the occurrence of different (optimal) paths converging to the same steady state. Due to the used numerical algorithm, based on continuation, we were able to detect such solutions also for our two species

4 - Growth and Collapse of Empires: A Dynamic Optimization Model

Gustav Feichtinger, Yuri Yegorov, Dieter Grass, Magda Mirescu, Franz Wirl

The paper addresses the spatial evolution of countries accounting for economics, geography and (military) force: Economic activity is spatially (uniformly) distributed following the AK model with output split into consumption, investment, transport costs and the military (for defense and expansion). The emperor controls the military force subject to the constraints from the economy and geography (transport costs, border length) and the necessity to satisfy the needs of the population. The border shifts depend on how much pressure the emperor can muster versus the pressure of the neighboring countries. The resulting dynamic process determines a country's size over time. The model leads to multiple steady states, large and small empires separated by a threshold, and collapse. The resulting pattern is linked to historical observations.

Tuesday, 12:30-14:00

■ TC-01

Tuesday, 12:30-14:00 - O'Reilly Hall

Claudia D'Ambrosio

Stream: Tutorials
Tutorial session
Chair: *Stéphane Dauzere-Peres*

1 - Challenging Optimization Problems in Energy Production and Transportation
Claudia D'Ambrosio

Management of energy systems is one of the biggest challenges of our time. The daily demand for energy increases constantly for many reasons. Moreover, the wide use of renewable energies, aimed at limiting polluting emissions, can create instability in the networks and uncertainty in energy production. In this context, Operational Research is a crucial tool that allows optimizing strategic, tactical, and operational decisions to be taken. After an overview of the most challenging problems in energy systems, we will focus on two among them: the hydro unit commitment and the phasor measurement units placement in smart grids.

The former is a production problem that is solved daily by utility companies. By its nature, it can be modeled as a mixed integer nonlinear program. Several objectives can be considered. We discuss different formulations and algorithmic solutions to tackle them, from the classical ones based on linearization techniques to more recent graph formulations.

The latter is a strategic problem aimed at making the grid observable, thus smarter. We introduce several equivalent formulations and discuss their advantages, drawbacks, and some tailored algorithms.

■ TC-02

Tuesday, 12:30-14:00 - Moore Auditorium

EDDA

Stream: EURO Doctoral Dissertation Award
Award Competition session
Chair: *Bernardo Almada-Lobo*

1 - Mathematical Programming Models and Algorithms for Offshore Wind Park Design
Martina Fischetti

Wind power is a fast-evolving field that has attracted a lot of attention and investment in recent decades. Its development into a more mature and competitive market is making cost reduction and maximisation of power generation imperative already in the design phase of new wind farms. Lower costs and increased power generation can be achieved through the use of optimisation tools based on mathematical models. We have therefore introduced Operational Research (OR) methods to identify the optimal location of wind turbines in a given site in order to maximise performance and ultimately profits. In this doctoral dissertation we developed a new wind farm layout optimiser in close cooperation between the Technical University of Denmark and Vattenfall BA Wind, a leader company in the energy business in North Europe. The position of each turbine in a wind farm and the routing and choice of cabling are extremely important and must be optimised to take into account such various factors as water depths, erosion zones, foundation costs, physical obstacles, cable loss and - most importantly - the wake effect, where one turbine casts a "wind shadow" on other turbines. All these factors can now be fully optimised and have a significant impact on the final layout and business case. The algorithms developed during the PhD are now fully deployed in the company and are used to design all Vattenfall's offshore wind farms. Due to the promising results obtained in the thesis, a new department of Operation Research and advanced modeling was created in Vattenfall. One of the main contributions of the thesis was a mathematical formalization of the problem, and the development of new models in accordance with the practical needs from the company. The very inter-disciplinary design of offshore wind farm has been fully captured using mathematical models, incorporating the expertise of many different groups of practitioners, and tested on real-life data. The design of wind farms proved to be a very challenging optimization task, mainly due to the large size of practical instances, complex constraints and the stochasticity of the wind. The advanced mathematical models and algorithms designed for the problem has been published in 5 high-level OR journals, as well as 3 book chapters, and numerous conference proceedings. The project received a finalist position or first prize in 6 international awards, including the very prestigious Franz Edelman Award.

2 - Linear and quadratic reformulations of nonlinear optimization problems in binary variables
Elisabeth Rodriguez-Heck

The problem of optimizing a multilinear polynomial on binary variables without additional constraints arises in a variety of applications. We are interested in resolution methods based on reformulations of this nonlinear problem into a linear or a quadratic one, an approach that attempts to draw benefit from the existing literature on integer linear and quadratic programming. In the context of linear reformulations we consider the standard linearization, a well-known reformulation method that consists in introducing an auxiliary variable to represent each higher-degree monomial, where the association of auxiliary variables to monomials is achieved using linear constraints. A first contribution of this thesis is a characterization of cases for which the continuous relaxation of the standard linearization provides integer solutions. Additionally, we define a class of valid inequalities called 2-links modeling interactions between pairs of intersecting monomials. For functions with exactly two nonlinear monomials, we prove that the 2-links together with the standard linearization inequalities completely describe the convex hull of their feasible integer points. Moreover, the 2-link inequalities strengthen the standard linearization and greatly improve resolution times for a class of specially structured problems. A broader definition is considered for quadratic reformulations: a quadratization is a quadratic function depending on the original variables and on a set of auxiliary binary variables, such that, when minimized only over the auxiliary variables, the original multilinear polynomial is recovered. We study several properties of quadratizations such as requiring a small number of auxiliary variables. A notable contribution is the definition of a quadratization for monomials with a positive coefficient using only a logarithmic number of variables, which improves previously published bounds by orders of magnitude. This result is especially interesting because every multilinear polynomial can be quadratized by reformulating its monomials separately. We also consider quadratizations of a different nature defined by splitting each monomial into two subterms to be associated with an auxiliary variable each. Defining such quadratizations using the smallest possible number of variables is an NP-hard problem, for which we define heuristic algorithms that identify sets of variables appearing frequently as a subterm of the original monomials, and substituting each set by the same auxiliary variable. Finally, this thesis presents a comparison of the resolution times of several linear and quadratic reformulations, using a commercial solver, over different classes of instances. Experimental results show that reformulations exploiting the structure of the original nonlinear problems, for example by better modeling interactions between monomials, have best resolution times for many instances.

3 - Incorporating Differential Equations into Mixed-Integer Programming for Gas Transport Optimization
Mathias Sirvent

In this thesis, we present new algorithms for mixed-integer programs with incorporated differential equations and show promising numerical results for our application of gas transport optimization.

Natural gas is one of the most important energy sources. In Germany, a politically intended energy turnaround has stirred up the way of power generation in the last decade and the proportion of natural gas rises slightly in that context and gives priority to questions of gas transport.

In particular, Germany does not have relevant gas fields and mainly Russia, the Netherlands, and Norway deliver the commodity. Consequently, gas transportation through pipelines and its mathematical optimization is a highly active field of research of applied optimization. Such optimization problems involve discrete decisions to switch network elements as valves, control valves, or compressor machines. Moreover, the physical behavior of natural gas is described by the Euler equations, which are a set of hyperbolic partial differential equations. Thus, when dealing with gas transport optimization, mixed-integer problems constrained by differential equations become relevant.

The challenging part emerges from the discrete aspects and from the differential equations. These equations are given as partial differential equations for transient gas transport optimization or as simplified ordinary differential equations for stationary gas transport optimization.

Mixed-integer programs including differential equations are typically solved by remodeling the differential equations to obtain an a-priori mixed-integer nonlinear or linear surrogate model. These remodeling steps are often subject to various simplification steps that are necessary to transform the differential equations into analytical functions. Our first challenge is to omit these simplification steps and develop general algorithms without relying on analytical functions. Moreover, we want to use the algorithms to solve stationary gas transport optimization problems that are constrained by ordinary differential equations.Furthermore, transient gas transport optimization often leads to huge mathematical programs after remodeling. In general, these problems cannot be solved when the size of the networks are of practical size. Our second challenge is to find formulations and corresponding algorithms that are able to tackle transient gas transport optimization problems. Note that the first challenge seeks for general algorithms that are then used for stationary gas transport optimization, whereas the second challenge is tailored to the application of transient gas transport optimization.

Our roadmap to cope with the challenges is inspired by two guidelines. We want to decompose our problems and we want to use mixed-integer linear programs. The simple reason for the first point is that decomposing problems into smaller ones has a successful history and is common sense for solving big problems. Second, mixed-integer linear programs underwent an enormous amount of research in the last decades. Consequently, fast, stable, robust, and reliable solvers as Gurobi, Cplex, or Scip are available and we use these solvers, in our case Gurobi, as a workhorse.

For the first challenge, we consider the case where the constraint functions of the differential equations are not given analytically. In general, a typical solution approach transforms the differential equations to linear constraints. The new global algorithms in this thesis do not rely on this transformation and can work with less information about the underlying differential equation constraints. We build up a new hierarchy of assumptions that restricts the knowledge about the nonlinear functions to a variable extent. Depending on the assumptions, we develop three new global decomposition algorithms that decompose the difficult constraints, i.e., we rely on our first guideline. In an iterative process, mixed-integer linear programs and small nonlinear programs are solved alternately and the correct and finite terminations of the algorithms are proven. Specifically, we build upon relaxation strategies that are motivated by developments in the field of (mixed-integer) (non)linear programming and Lipschitz optimization. As a result, mixed-integer linear programs according to our second guideline are obtained. We prove correct and finite terminations and clarify the limitations of our approaches. Note that the presented framework is a general approach for mixed-integer programs with differential equations. In particular, we consider stationary gas transport optimization and show promising numerical results for the real-world gas network of Greece.

Additionally, we consider the second challenge of transient gas transport optimization. We use an instantaneous control algorithm and adapt it to the Euler equations for the first time. Specifically, we decompose the problem into single time steps and present new discretization techniques that ensure the mixed-integer linear program property for the occurring problems. In other words, we build upon our guidelines again. Finally, we show promising numerical results that illustrate the applicability of the approach.

■ TC-03

Tuesday, 12:30-14:00 - Q106

Roundtable 1: Making an impact across the industry

Stream: Practice of OR (Making an Impact)
Award Competition session

Chair: *Jean André*
Chair: *Jean André*
Chair: *Jean André*

1 - Roundatble 1: Making an impact accross the industry
Jean André

Around this roundtable, the panel will talk about the key performance indicators (economical, environmental...) industrial companies are trying to optimize jointly or separately (included or not in the models), the impact through examples on the operations to transform the way they work, the integration within their working environment and processes (user interactivity, HMI and others), the qualitative benefits such as team training, knowledge sharing... They will also cover the challenges of understanding the business needs and transform it iteratively into optimization models, the modeling effort to capture all the dynamic situations faced by operations, the difficulties of user acceptance vs the other tools they have used in the past (comparative effect) or home made tools or well marketed magic tools, how they are guaranteeing the actual use...

■ TC-04

Tuesday, 12:30-14:00 - Q116

Teaching OR/MS 3

Stream: OR Education
Invited session

Chair: *Socorro Rangel*

1 - Embedding Basic Operations Research Techniques in Nursing Education and Practice: Opportunities, Challenges, and Lessons Learned
Sara McComb

Improving our healthcare systems is a complex imperative that can only be done through collaboration. Nurses are at the frontline of healthcare and, therefore, are in the best position to understand where the system impedes their day-to-day delivery of care. Yet, most operational research efforts focus on incorporating the physician perspective. This paper describes how basic systems thinking, quality improvement, and operational research education has been integrated into the nursing curricula across levels from baccalaureate to doctoral. The approach required scaffolding learning across levels that is sustainable; fostering nursing faculty involvement and building their competency; cultivating partnerships within and outside the academy; increasing interprofessional opportunities for undergraduate, graduate, and faculty nurses and operations researchers; and heeding our own lessons learned. The result of this integration is a cadre of nurses (1) prepared to make basic improvements themselves and use data to articulate issues they face and (2) possessing an appreciation of the tools and techniques available for enhancing healthcare delivery and the ability to engage more actively with operations researchers who have the expertise to apply those methods. Operations researchers engaged with nurses in interprofessional activities have also benefitted as they gained an appreciation for how nursing expertise can enrich their efforts to improve healthcare delivery.

2 - Problem solving and optimization as a teaching strategy for mathematics. Experiences and perspectives
Antonio Sforza

In the last 10 years, several institutions in the Campania Region have carried out a series of initiatives aimed at preparing students in the region to take part in the OCSE-PISA mathematics test, based on the concept of problem solving, which is beginning to be addressed in mathematics teaching. In this context, the Education Department of the Campania Region promoted two courses, Logimat and Logimat2, on logical-mathematical learning. The scope was to train mathematics teachers in secondary schools, as part of an agreement between the Ministry of Education and the Campania Region, which establishes initiatives aimed at supporting the education of mathematics, science and technology in schools and promoting didactic innovation. After this the Naples Science Centre, promoted the Project LogicaMente. Finally, Campania Office of the Ministry of Education implemented another initiative devoted to developing the problem solving approach in the teaching of mathematics in secondary schools. The Project - OCSE PISA - Objective 500, aimed to increase proficiency of fifteen year old students in Campania, to achieve the score of 500 in the OCSE PISA test. The project was biennial and 80 schools participated in the initiative. In the last three years, the University Federico II of Naples set up the F2S group (Federico II in School) to build a link between schools and university, with the aim of preparing students for the university experience, developing effective multimedia tools.

3 - Teaching combinatorial optimization to secondary school students: traveling around 20 Brazilian cities
Socorro Rangel

In this talk we present our experiences conducting workshops to secondary school students introducing combinatorial optimization problems. The objective is to stimulate the students' interest in the study of mathematics. The proposed activity has an interdisciplinary character and consists in determining a travel itinerary that includes 20 Brazilian cities, bringing the "Game of Hamilton" (Icosian Game, or A Voyage around the world) to the Brazilian context. During the activity we give a brief presentation of graph theory and of the Traveling Salesman Problem (TSP). Using the concept of permutation, we discuss the computational difficulties of the problem and the idea of heuristic algorithms. To conclude the workshop, a discussion is proposed about the importance of the TSP in the solution of other "real life" problems. (Thanks are due to the Brazilian agency FAPESP (2016/01860-1, 2013/07375-0))

■ TC-05

Tuesday, 12:30-14:00 - A003

Spatial Risk Analysis

Stream: Decision Analysis
Invited session
Chair: *Nikolaos Argyris*
Chair: *Valentina Ferretti*
Chair: *Simon French*

1 - "Birds of a Feather" Fail Together: Exploring the Nature of Dependency in SME Defaults
Raffaella Calabrese, Galina Andreeva, Jake Ansell

his article studies the effects of incorporating the interdependence among London small business defaults into a risk analysis framework using the data just before the financial crisis. We propose an extension from standard scoring models to take into account the spatial dimensions and the demographic characteristics of small and medium-sized enterprises (SMEs), such as legal form, industry sector, and number of employees. We estimate spatial probit models using different distance matrices based only on the spatial location or on an interaction between spatial locations and demographic characteristics. We find that the interdependence or contagion component defined on spatial and demographic characteristics is significant and that it improves the ability to predict defaults of non-start-ups in London. Furthermore, including contagion effects among SMEs alters the parameter estimates of risk determinants. The approach can be extended to other risk analysis applications where spatial risk may incorporate correlation based on other aspects.

2 - Spatial Transmission Models: A Taxonomy and Framework
Duncan Robertson

Within risk analysis and, more broadly, the decision behind the choice of which modeling technique to use to study the spread of disease, epidemics, fires, technology, rumors, or, more generally, spatial dynamics, is not well documented. While individual models are well defined and the modeling techniques are well understood by practitioners, there is little deliberate choice made as to the type of model to be used, with modelers using techniques that are well accepted in the field, sometimes with little thought as to whether alternative modeling techniques could or should be used. In this article, we divide modeling techniques for spatial transmission into four main categories: population-level models, where a macro-level estimate of the infected population is required; cellular models, where the transmission takes place between connected domains, but is restricted to a fixed topology of neighboring cells; network models, where host-to-host transmission routes are modeled, either as planar spatial graphs or where shortcuts can take place as in social networks; and agent-based models that model the local transmission between agents, either as host-to-host geographical contacts, or by modeling the movement of the disease vector, with dynamic movement of hosts and vectors. We summarize these techniques by introducing a taxonomy classifying these modeling approaches. Finally, we present a framework for choosing the most appropriate spatial modeling method.

3 - Just Society : A Decision Theoretic Approach
Rakesh Sarin

In this presentation, I will present a decision theoretic justification for the design of a society that maximizes individual happiness. I will show that behind a veil of ignorance where an individual does not know his/her economic and social position, a rational person will choose institutions of the society that aim towards maximizing expected utility subject to a social minimum.The approach will be compared with Rawls maximin and Bentham's utilitarian approaches. I will make preliminary observations on the European vs the US system.

4 - Advances in Spatial Risk Analysis
Nikolaos Argyris, Valentina Ferretti, Simon French, Gilberto Montibeller

We live in a 3D world with increasing availability of real time spatial data, from satellite information, mobile tracking, autonomous transportation systems, among many other sources. Such availability of data, together with increasingly sophisticated risk and decision analytic frameworks, is enabling more effective support in answering questions such as: • How to plan the growth of cities in a sustainable way? • Where to bury nuclear waste? • Where to increase flood defenses? • What is the likely spatial spread of a disease? • How will airborne or waterborne contamination disperse? • What is the likely impact region of a satellite in a decaying orbit? • How to distribute police on open patrol in a large city? • How to assess the chance of finding a missing aircraft over a wide area?

Such questions were addressed by articles appearing in a recent Special Issue on Spatial Risk Analysis of the journal Risk Analysis, which we have co-edited.

In this talk put forward a five-stage framework for Spatial Risk Analysis. We use this to discuss the contributions of the Special Issue articles and highlight areas where further research is needed.

■ TC-06

Tuesday, 12:30-14:00 - A004

Modelling integrated power and gas systems

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Hans Christian Gils

1 - Facilitating renewables and power-to-gas via integrated electrical power-gas system scheduling
Kenneth Bruninx, Andreas Belderbos, Thomas Valkaert, Erik Delarue, William Dhaeseleer

The possibly increasing volatile gas off-take from gas-fired power plants to accommodate volatile renewable generation in combination with the integration of power-to-gas (P2G) warrants further study into the operation of a coupled electrical power and natural gas system. Therefore, in this talk, we present the formulation and validation a novel operational model comprising both the electrical power and gas systems. Model improvements include (i) the use of zonal gas loads in addition to nodal loads, (ii) ramp rates for conventional gas production facilities and (iii) a detailed technological model of P2G units. Results of several small-scale case studies illustrate the relevance of these model additions. In addition, a case study inspired by the Belgian electrical power and gas system shows that the Belgian gas network has abundant capacity to integrate a possibly volatile injection of synthetic methane from P2G. This model may be used by electricity and gas transmission system operators to study the interaction between their systems and inform policy makers and regulator.

2 - Solving the integrated optimal power and gas flow problem for large transmission networks
Lukas Löhr, Raphaël Houben, Albert Moser

The integrated modeling of power and gas systems is gaining in importance as a result of climate policy discussions on sector coupling. Power-to-Gas systems increase the interdependencies of the classic optimal power and gas flow problem (OPGF), which aims to minimize economic dispatch costs and is mostly applied to small test systems. However, to investigate the system wide effects of sector coupling, large transmission networks must be considered, where the gas flow is the greatest challenge. This results from nonlinearities, which occur especially due to the pressure loss equations and lead to a mixed integer nonlinear optimization problem. This paper solves the OPGF as mixed-integer linear problem with piecewise linearization of the pressure loss equation and a DC power flow. By this, the approach reduces computation time to apply this model to large systems. Coupling of power and gas networks is bidirectional through the consideration of power-to-gas, gas-to-power plants as well as hybrid consumers. In addition to the piecewise linearization modeled as Special-Ordered-Sets-Constraints, integrality results from optionally added binaries to model switching decisions for power plants. This paper solves the modeled OGPF with CPLEX or Gurobi and compares quality and computation time for different network sizes with the nonlinear formulation solved by IPOPT. For this purpose, performance in different sized IEEE test systems for power and OGE networks for gas is compared.

3 - Integrated modelling of the future electricity and gas supply in Germany
Hans Christian Gils, Hedda Gardian

The project "MuSeKo" aims to investigate the use of different technology options for the flexible use of electricity in all sectors of the energy system with an integrated model-based analysis. A special focus lies on the connection of business and macro-economic perspective by iterative simulations. One objective is the evaluation of economic efficiency, investment incentives and regulatory framework conditions. As part of the project, the REMix energy system model was expanded to include the gas sector. In addition to the production and conversion of synthetic fuels, this also includes the storage and transport of gases and their use in the electricity and heat sectors. The extended model allows the integral consideration of the electricity and gas system as well as the associated elements of the heat supply and transport sector. For different scenarios, the paper shows the impact of the energy system transformation on the use of the gas infrastructure, the possible contribution of an adapted operation of the electrical equipment in the gas network to the integration of fluctuating renewable power generation, and the potentials of the production and use of synthetic fuels (hydrogen, natural gas). Furthermore, the demand for different types of storage (power, heat, gas) as well as converters (e.g. heat pumps, cogeneration, hydrogen electrolysers and methanation facilities) in an integrated energy future energy system with high renewable energy supply share is evaluated.

4 - Economic impacts of uncertainty in integrated electricity and gas markets
Iegor Riepin, Thomas Moebius, Felix Muesgens

The paper focuses on the evaluation of economic impacts of uncertainty drivers on the interdependent electricity and gas markets. We track the effects of uncertain economic, technological, and regulatory factors on the integrated system. We utilize a stochastic two-stage cost-minimization model of integrated European power and gas systems. The model simulates the multistage nature of investment planning under uncertainty - the first-stage investments decisions must be made before the information on uncertain factors is revealed. The model includes relevant infrastructure elements and cost estimators for European energy production and transport. We combine the two markets via fuel linkage: both the gas demand for power sector and the price for gas-fired generation are modelled as endogenous variables. The benefit of using a global objective in the integrated modelling is that we obtain reliable marginal costs estimators on both the electricity and natural gas markets. Our results provide a comparison of the expected costs of ignoring uncertainty for various parameters and a sensitivity to different uncertainty ranges. Furthermore, we highlight that the evaluation of economic impacts of uncertainty requires an integrated modelling approach because neglecting feedback effects across the energy systems leads to results with systematic errors.

■ TC-07

Tuesday, 12:30-14:00 - A007

Agri-Food supply chain

Stream: OR in Agriculture and Forestry
Invited session
Chair: Marina Segura

1 - A bilevel program for a two-echelon agribusiness supply chain
Victor M. Albornoz

A linear mixed-integer bilevel programming model for an agribusiness two-echelon supply chain between an agro-industrial producer and a wholesaler is presented. The model includes a hierarchical decision structure that contemplates an agro-industrial producer in the upper level, which maximizes it profit by delineating the field into management zones and assigning to each one a specific crop rotation plan, while in the lower level is the wholesaler who minimizes the cost of unmet demand according to the units provided by the producer. We solved a case study to show the relevance of the proposed methodology. The results achieved with this methodology, conclusions, and possible extensions of this research will be presented.

2 - Sustainability assessment of Logistics strategies within Food Supply Chains: Case Study of a Regional Food Network in Linz, Austria
Ani Melkonyan, Tim Gruchmann

Current trends related to increased sustainability requirements of food production and consumption systems, application of new digital technologies and changed consumer behavior have disrupted food supply chains, meanwhile entailing challenges for the last mile logistics. To investigate sustainability along food supply chains the evolution of integrated solutions linking all the key actors, synchronization of a public/private e-marketplace, and developing sustainable logistics strategies is necessary, which is the main aim of this study. The following research question was thus raised: what kind of management strategies can be developed and implemented in order to combine the interests and requirements of the key actors along the food supply chain and how can related business models be transformed? Advanced qualitative and quantitative methods (System Dynamics modeling and multi-criteria decision making) have been applied to assess operational and strategic indicators based on a concrete case study in the food industry. The results showed that a diffusion of food networks and logistics service providers can be the basis for developing sustainable business models, if the logistics sector proactively innovates the service portfolios, while making sustainability choices easier for the customers. This innovation can be reached by integrating production and consumption patterns while making the horizontal and vertical supply chains more transparent.

3 - A multiple criteria approach to evaluate the sustainability of products and suppliers in food distribution companies

Marina Segura, Concepción Maroto, Baldomero Segura

Sustainable Supply Chain Management should integrate all dimensions of sustainability: economic, environmental and social. Nevertheless, the latest advances are only focused on economic and environmental criteria and there is a lack of social indicators in the empirical research. Multiple Criteria Decision Making plays an increasing role because of its ability to balance the conflicting criteria, both tangible and intangible. Multiple criteria techniques have been mainly applied in the supplier selection in manufacturing sectors, such as automotive and electronics among others, while there are hardly any applications to agrifood sector, which has special characteristics. This paper proposes a system to evaluate fresh food to qualify products and then, together with other criteria, evaluate suppliers in order to increase the efficiency of the food supply chain, and improve the quality and safety of food. First, we defined the criteria related to products: product cost, value-added, conformance to specification, rejection rate, quality and environmental management systems, traceability, safe quality food certifications and eco-labelling. In addition, among the supplier criteria we have included service quality, complaints, product recall, green image and communication. Second, value function and outranking methods have been used to obtain indicators for products and suppliers. Finally, a case study with an application to fruits in a supermarket chain is presented.

■ TC-08

Tuesday, 12:30-14:00 - A008

Multistage stochastic programming: theory, applications and algorithms

Stream: Stochastic and Robust Optimization

Invited session

Chair: Milos Kopa

1 - Nested Risk Measures for Diffusion Processes

Ruben Schlotter, Alois Pichler

We introduce nested risk measures for stochastic processes and extend the infinitesimal generator to the risk averse case. Nested risk measures are built on static risk measures, which originate by conditioning on the history of a stochastic process. These nested risk measures appear naturally in the context of multistage optimization, as they allow beneficial reformulations for algorithmic treatments. We extend the notion of a nested risk measure to continuous time and derive a risk-averse analogue to the infinitesimal generator, a nonlinear partial differential operator. Using the concept of a risk-averse generator we obtain a risk-averse Hamilton-Jacobi-Bellman equation. Finally we relate our results with risk measures defined via g-expectation and characterize their drivers in relation to nested risk measures.

2 - Stochastic optimization controlled at random decision points

Petr Lachout

We consider a random process dynamically developing in time. The process is controlled at nodes of a given graph which are active. Properties of nodes are changing and developing in time according to endogenous randomness. The task is to optimize gain from the random process using control on the given graph. We intent to give a description of the random process and present some basic relations, and results.

References: [1] Bonnans J.F., Shapiro A.: Perturbation Analysis of Optimization Problems. Springer-Verlag, New York, 2000 [2] Rockafellar R.T., Wets R. J.-B.: Variational Analysis. Springer-Verlag, Berlin, 1998. [3] Shapiro A., Dentcheva D., Ruszczynski A.: Lectures on Stochastic Programming: Modeling and Theory. MPS-SIAM, Philadelphia, 2009.

3 - A BFC-based matheuristic algorithm for multistage mixed convex stochastic problems

Eugenio Mijangos

We present a matheuristic algorithm to solve multistage mixed 0-1 stochastic problems with nonlinear convex objective function and convex constraints. These problems have continuous and binary variables in each stage and the number of contingencies of the nodes is not the same in at least one stage, i.e. the uncertainty is represented by a non-symmetric scenario tree. The algorithm is based on the Branch-and-Fix Coordination method (BFC) modified to get a higher efficiency. Some heuristic criteria are proposed in order to reduce the number of Twin Node Families visited during the performance of the algorithm, which are numerically tested. In order to solve each nonlinear convex subproblem generated at each node of the trees of the BFC method we propose to use sequences of quadratic problems. The algorithm has been implemented in C++ with the help of Cplex to solve quadratic subproblems. Test problems have been randomly generated by a C++ code. Computational tests have been performed and its efficiency has been compared with that of MINLP codes.

4 - Producer's Best Response in Pay-as-clear Electricity Market with Stochastic Demand

Martin Branda, Didier Aussel, Rene Henrion, Miroslav Pištěk

The non-cooperative characteristic of electricity markets led to concentrate on Nash equilibria and multi-leader-follower games, where the producers of electricity are viewed as leaders while the regulator of the market, referred as the Independent System Operator (ISO), is viewed as the common follower. In this work, to deal with the stochastic demand we employ the so-called chance constrained formulations of the problem of the ISO as well as the problem of each producer. In detail, the ISO minimizes the production cost using a chance constrained approach approach, thus hedging against discrepancies between estimated and real electricity demand. Similarly, in the day-ahead market, each producer is hedging against the uncertainty of his own prediction of the demand using value-at-risk (VaR) measure. In such a setting we aim at determining the "best response" of a given producer, i.e. the bid maximizing its profit. To illustrate our results, we provide a numerical evaluation based on the historical distribution of both estimated and real electricity demand using French market data. We determine the optimal production of electricity given the probability prescribed to satisfy the aggregated demand. Then, we prepare a numerical simulation with five producers and find the best response of each of them.

■ TC-09

Tuesday, 12:30-14:00 - B006

Performance Measurement I

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Dimitris Despotis*

1 - Extension of inverse data envelopment analysis to a serially linked two-stage process
Don Galagedera

DEA models generally assess relative performance with observed inputs and outputs whereas inverse DEA models estimate outputs (inputs) that maintains a given level of performance of a DMU when its inputs (outputs) change. DMU growth, merger and acquisition are typical applications of inverse DEA. Several variants of the basic inverse DEA model are available in the literature. However, they are predominantly on single-stage production processes. In this paper, we formulate an output-oriented inverse DEA model for the serially linked two-stage production process. We develop a multi-objective optimisation problem (MOOP) to determine intermediate and output targets for a virtual DMU (created by augmenting the inputs of an observed DMU) to maintain its overall efficiency at a pre-specified level. We propose a two-step solution procedure after reducing the MOOP to a single-objective optimisation problem and a procedure to decompose the overall efficiency of a virtual DMU at the stage level. We highlight through an empirical investigation that information on potential effects of DMU growth, merger or acquisition obtained through inverse DEA prior to their implementation aid decision-making and resource planning. Inverse DEA analysis provides insights on potential outcomes prior to making a decision. The theoretical results that we present paves the way for extending the proposed output-oriented inverse DEA methodological framework to the input-oriented multi-stage case.

2 - A Linear programming model for generating positive weights in DEA
Paul Rouse, Dimitris Margaritis, Maryam Hasannasab, Israfil Roshdi

There is no guarantee that the optimal multipliers obtained from a Data Envelopment Analysis model are always positive. Often the LP solution returns zero multiplier weights for inputs and outputs as a result of the Simplex algorithm stopping once it has found an optimal feasible solution. A problem arises when the weights are to be used in further analyses such as estimating marginal productivity, rates of transformation and substitution, the relative importance of inputs and outputs and scale elasticity using the multipliers. These measures can be affected by the presence of zero weights and yield unrealistic values. A valid and more reasonable value can be obtained by consideration of an optimal solution with a minimum possible number of zero weights. In this paper, we offer two LP models. The first LP generates a profile of weights with a maximum number of positive weights. This LP allows weight flexibility while finding a set of weights with the most possible positive elements independent of the solver. The second LP, provides a profile of weights with the same characteristic but is specific to each DMU. Additionally, it recognises the Pareto efficient DMUs and introduces the maximal reference set for the DMUs which are not Pareto efficient. This extends previous work by Bougnal, Dula and Rouse (2012) which used interior point methods to obtain non-zero multiplier weights, and has the attraction that the issue of weight positivity is directly addressed in our LPs.

3 - A LINGO/MS Excel system for solving data envelopment analysis models
Josef Jablonsky

Data envelopment analysis (DEA) models are tools for efficiency and performance evaluation of a set of decision-making units (DMUs). They are formulated as linear programming problems that have to be solved for each DMU of the given set. The paper discusses problems with solving DEA models and presents an original system written in LINGO modeling language and using MS Excel as the user's interface. This system covers main DEA models including multiplier and envelopment models, models for ranking of DMUs, network models, models with uncontrollable variables, models with undesirable outputs, etc. Depending on the version if the LINGO system the DEA solver can analyze problems from 200 until the unlimited number of DMUs.

4 - On the dominance property in Network Data Envelopment Analysis
Dimitris Despotis, Gregory Koronakos, Dimitrios-Georgios Sotiros

We introduce the notions of Pareto optimality and dominance at the divisional efficiencies level in network DEA. We investigate the dominance property for representative models and methods drawn form both the top-down and bottom-up approaches in network DEA. In the top-down approach, the overall system efficiency is optimized first, and the divisional efficiencies derive as offspring from the optimal solution that maximizes the system efficiency. This requires an a priori definition of the overall system efficiency. According to the bottom-up approach, the divisional efficiencies are estimated first and the system overall efficiency is derived ex post. The methods proposed in the literature differ in the way they assess the divisional efficiencies and the functional form used to define the system efficiency. We show that the two characteristic methods within the top-down approach, namely the additive decomposition method and the relational model satisfy the dominance property only in the elementary two-stage network structure and we provide counter examples that reveal the violation of the dominance property in general two-stage structures. Then, we revisit some characteristic methods that follow the bottom-up approach, for which dominance in the divisional efficiencies space is an inherent property.

■ TC-10

Tuesday, 12:30-14:00 - H0.12

Recent Progresses in Derivative-free Optimization

Stream: Derivative-free Optimization
Invited session
Chair: *Ana Luisa Custodio*

1 - A merit function approach for evolution strategies to handle constrained optimization problems.
Youssef Diouane

In this work, we extend a class of globally convergent evolution strategies to handle general constrained optimization problems. The proposed framework handles relaxable constraints using a merit function approach combined with a specific restoration procedure. The unrelaxable constraints in our framework, when present, are treated either by using the extreme barrier function or through a projection approach.

The introduced extension guaranties to the regarded class of evolution strategies global convergence properties for first order stationary constraints. Preliminary numerical experiments are carried out on a set of known test problems as well as on a multidisciplinary design optimization problem.

2 - A global optimization algorithm for constrained blackbox problems
Phillipe Sampaio, Philippe L. Toint

The fast-growing need for simulation-based optimization methods in fields such as medicine, chemistry and engineering, has contributed for the design of new efficient algorithms for finding the best possible solution. In this work, we present DEFT-FUNNEL, a global optimization algorithm for constrained black-box problems that belongs to the class of trust-region sequential quadratic programming algorithms. Polynomial interpolation models are used as surrogates for the black-box functions and a clustering-based multi-start strategy is applied for searching for the global optimum. We show that our algorithm compares favorably with other state-of-the-art methods on a test problem set.

3 - Derivative-free optimization for a noisy optimization problem in fisheries science
Ute Schaarschmidt, Trond Steihaug

We present results from application of derivative-free optimization methods to estimate the parameters in ordinary differential equations (ODEs). The aim is to find parameters which minimize a function of a numerical solution of a differential equation and available data. Our choice of class of optimization method is motivated by the fact that the objective function may be distorted by computational noise arising from numerical solution of the ODE. A further challenge for optimization is that the ODE solver may unexpectedly fail to return a value, resulting in constraints which are hidden from the problem formulation.

As an example, we consider systems of stiff ODEs with two distinct time-scales that describe the dynamics of a fish population. The performances of five derivative-free optimization methods are compared based on efficiency, the robustness to the initial iterate, and the robustness to the non-linearity of the differential equation. Using numerical simulations, we demonstrate that several classes of derivative-free optimization methods find sufficiently accurate solutions for the noisy optimization problems with hidden constraints.

4 - Calibration of parameters in Dynamic Energy Budget models using Direct-Search methods
Ana Luisa Custodio, Jéssica Morais, Gonçalo Marques

Dynamic Energy Budget (DEB) theory aims to capture the quantitative aspects of metabolism at the individual level, for all species. The parametrization of a DEB model is based on information obtained through the observation of natural populations and experimental research. Currently the DEB toolbox estimates these parameters using the Nelder-Mead Simplex method, a derivative-free direct-search method. However, this procedure presents some limitations regarding convergence and how to address constraints.

Framed in the calibration of parameters in DEB theory, this work presents a numerical comparison between the Nelder-Mead Simplex method and the SID-PSM algorithm, a Directional Direct-Search method for which convergence can be established both for unconstrained and constrained problems. A hybrid version of the two methods, named as Simplex Directional Direct-Search, provides a robust and efficient algorithm, able to solve the constrained optimization problems resulting from the parametrization of the biological models.

■ TC-12

Tuesday, 12:30-14:00 - H1.51

Techniques in Combinatorial Optimization

Stream: Combinatorial Optimization I
Invited session
Chair: Laura Galli

1 - New Valid Inequalities for the Fixed-Charge Polytope
Georgia Souli, Adam Letchford

Algorithms and software for integer programming and combinatorial optimisation have improved dramatically over the past couple of decades. A key source to this success is the use of strong valid linear inequalities, also known as cutting planes. In 1985, Padberg, Van Roy and Wolsey considered problems that involve fixed charges, and introduced a procedure which enables one to take known valid inequalities for the knapsack polytope, and convert them into valid inequalities for the fixed-charge polytope. In this talk, we show how this procedure can be extended to obtain a much wider family of inequalities, that are very different from the previously known inequalities, such as flow cover and flow pack inequalities.

*This is joint work with Adam N. Letchford.

2 - On Surrogate and Composite Relaxations of Combinatorial Optimisation Problems
M Hasan Mansoor, Adam Letchford, Trivikram Dokka

Relaxation techniques have proven to be very effective for computing bounds for combinatorial optimisation problems. Among the available relaxation techniques, the most well-known are probably linear, semidefinite and Lagrangian relaxation. Surrogate relaxation (SR) and composite relaxation (CR) are less well known than their close cousin, Lagrangian relaxation, but they are potentially more powerful. We present some new observations on the computational complexity of certain problems that arise when applying SR and CR to combinatorial optimisation problems. We then propose some heuristics for selecting multipliers. Finally, we present some computational results, obtained by applying SR and CR to the three-index assignment and simple plant location problems.

3 - Facets from Gadgets
Adam Letchford, Anh Vu

We present a new tool for generating cutting planes for NP-hard combinatorial optimisation problems. It is based on the concept of "gadgets"—small subproblems that are "glued" together to form hard problems—which we borrow from the literature on computational complexity. Using gadgets, we are able to derive huge (exponentially large) new families of strong (and sometimes facet-defining) cutting planes, accompanied by efficient separation algorithms. We illustrate the power of this approach on the asymmetric traveling salesman, stable set and clique partitioning problems.

4 - Using Bit Representation to Improve SDP Relaxations of Mixed-Integer Quadratic Programs
Laura Galli, Adam Letchford

A standard trick in integer programming is to replace bounded integer variables with binary variables, using a bit representation. In a previous work, we showed that this process can be used to improve linear programming relaxations of mixed-integer quadratic programs. Here we show that it can also be used to improve semidefinite programming relaxations.

■ TC-13

Tuesday, 12:30-14:00 - H2.12

(Semi) Infinite Optimization

Stream: Nonlinear Programming. Theory and Methods
Invited session
Chair: Maria Dolores Fajardo
Chair: *Margarita Rodríguez Álvarez*

1 - Voronoi diagrams of arbitrary sets via linear semi-infinite systems
Miguel Goberna

Given an arbitrary set T in the Euclidean space R^n, whose elements are called sites, and a particular site s, the nearest (farthest, respectively) Voronoi cell of s consists of all points which are closer (farther) from s than from any other site. The nearest (farthest, respectively) Voronoi diagram of T is the family of all nearest (farthest) Voronoi cells. This talk compares nearest and farthest Voronoi cells and diagrams by exploiting the representations of both types of cells as solutions sets of linear semi-infinite systems.

2 - Even Convexity
Margarita Rodríguez Álvarez, José Vicente-Pérez, Miguel Goberna

A set is evenly convex if it is the intersection of some family (possibly empty) of open halfspaces. This class of convex sets was introduced by Fenchel in 1952 in order to extend the polarity theory to nonclosed convex sets. In the eighties, Martínez-Legaz and Passy and Prisman, independently, started to use evenly convex sets in quasiconvex programming defining the evenly quasiconvex functions as those having evenly convex sublevel sets. In this talk, we consider the class of evenly convex sets as an extension of the closed convex sets one and show that it captures the most outstanding properties of this subclass. Moreover, we define the so-called evenly convex functions as those functions whose epigraphs are evenly convex and study the main properties of this class of convex functions that contains the important class of lower semicontinuous convex functions.

3 - Saddle point theory in evenly convex optimization
Maria Dolores Fajardo

There exists a closed relation between saddle point theory and total duality in convex optimization, in the sense that saddle points can be characterized in terms of optimal solutions for the primal problem and the dual one. Moreover, under strong duality, the set of multipliers is the set of solutions of the dual problem, and it is also related with the subdifferential set at zero of the infimum value function when the perturbational approach of duality theory is considered. In this work we analyze all these properties and relations in evenly convex optimization, where a generalized conjugation scheme is used instead of the classical Fenchel one.

4 - Singular Optimization and p-Regularity Theory
Agnieszka Prusińska, Ewa Bednarczuk, Alexey Tretyakov

We present recent advances in the analysis of operator equations with singular operators and constrained optimization problems with constraints given by singular mappings obtained within the framework of the p-regularity theory developed over the last twenty years. In particular, we address the problem of description of the tangent cone to the solution set of the operator equations, optimality conditions and solution methods for optimization problems.

■ TC-14
Tuesday, 12:30-14:00 - H2.20

Decomposition Methods II

Stream: Mixed Integer Programming
Invited session
Chair: *Stephen Maher*
Chair: *Ibrahim Muter*

1 - Partial Path Relaxation
Diego Pecin, Twan Dollevoet, Remy Spliet

We study a class of binary programming problems with a large number of decision variables. We specifically focus on problems in which the decision variables correspond to the selection of paths. In many applications this setting can be recognized, e.g., in vehicle routing and crew scheduling. To solve such problems, we propose a reformulation in which we represent paths using partial paths, and replace the decision variables correspondingly. As a result of this partial path relaxation, the LP bound becomes weaker. However, the LP bound might also be easier to compute. In particular, when employing a column generation algorithm, the complexity of the pricing problem might change as a result of the relaxation. This trade-off can be leveraged to reduce computation time and memory required by a branch-and-price algorithm. We present this concept as a generic framework, and explore several different partial path relaxations and analyze the complexity of the corresponding pricing problems. Moreover, we illustrate the concept by performing numerical experiments.

2 - Benders for the Rich VRP
Arthur Mahéo, Philip Kilby

We look at a tender for delivering groceries in Queensland, Australia, which combines decisions about the fleet composition and evaluation of the routes given a year of demand. The routing problem is further complicated by compatibility constraints as part of the commodity is chilled and requires refrigerated transportation.

In full, this is an istance of a Fleet-Size-and-Mix Vehicle Routing Problem. This problems seems amenable to a Benders decomposition: first, determine the fleet; second, calculate the cost of routing vehicles. However, because the routing problem contains integer variables, we cannot use a classic Benders approach.

We propose a new branch-and-cut framework where: - Benders cuts are derived from the LP relaxation of the sub-problem at integer nodes, as such they may cut-off the optimal solution; - a heuristic compensates the loss of information by providing a valid bound. The combination of the two means we have a gap where candidate solutions cannot be pruned, these are solved to integer optimality in a post-processing phase.

By delaying solving the sub-problem until after the branch-and-cut, we solve less than half as much problems to integer optimality. During the branch-and-cut, we can leverage information from the master problem to decrease the computational effort – such as which is the best fleet for each day.

3 - A Benders' decomposition framework for solving MINLPs in SCIP
Stephen Maher, Stefan Vigerske

As general purpose Benders' decomposition frameworks emerge, applying this popular algorithm to a wider range of problem classes is becoming increasingly more important. Mixed-integer non-linear programs (MINLP) are an important class of problems arising from industry, however, there are limited resources for simple application of decomposition techniques to solve them. While Benders' decomposition has been successfully applied to MINLPs in the past, the development of a general purpose framework for such problems has not been fully investigated. A number of extensions to the Benders' decomposition framework within SCIP have been made to enable the solving MINLPs as the master or subproblems, including the addition of cut generation methods and subproblem solving routines. Through a number of examples, include the quadratic stochastic facility location problem, we demonstrate the potential of solving decomposable MINLPs with a general purpose Benders' decomposition framework. Extending the Benders' decomposition framework within SCIP will enable the wider application of this algorithm to a larger class of mathematical programming problems.

■ TC-15
Tuesday, 12:30-14:00 - H2.32

Multiobjective Optimization for Differential Equations and Decision Making

Stream: Multiobjective Continuous Optimization
Invited session
Chair: *Stefan Volkwein*
Chair: *Michael Dellnitz*

1 - Non-Convex Pareto Front Navigation
Dimitri Nowak

In the industry, many problems can be formulated as multicriteria optimization problems (MOP) with oftentimes conflicting objectives, e.g., cost versus quality. Such problems do not offer one unique solution. Instead, they imply a set of best alternatives. The computation of this so-called Pareto set is the goal of multicriteria optimization.

The computation of the Pareto set can be quite difficult, even in cases where the optimization problem has a complete analytical representation. In practice, it is easier to switch in the objective space, the evaluation of alternatives, to compute the Pareto front. Then, the Pareto front is approximated by a finite set of Pareto points and interpolated to offer the decision maker a continuous exploration of the Pareto set.

The exploration of best alternatives, which we call navigation, is well established for convex MOPs. In the non-convex case, however, the navigation is still challenging. In this talk, a new interactive approach to navigate on Pareto front approximations is discussed. With an emphasis on efficiency, real time navigation in the vicinity of non-convex Pareto front is made possible.

2 - Inverse multiobjective optimization: Inferring decision criteria from data
Bennet Gebken

It is a very challenging task to identify the objectives on which a certain decision was based, in particular if several, potentially conflicting criteria are equally important and a continuous set of optimal compromise decisions exists. This task can be understood as the inverse problem of multiobjective optimization, where the goal is to find the objective vector of a given Pareto set. To this end, in this talk we will present a method to construct the objective vector of a multiobjective optimization problem (MOP) such that the Pareto critical set contains a given set of data points or decision vectors. The key idea is to consider the objective vector in the multiobjective KKT conditions as variable and then search for the objectives that minimize the Euclidean norm of the resulting system of equations. By expressing the objectives in a finite-dimensional basis, we transform this problem into a homogeneous, linear system of equations that can be solved efficiently. There are many important potential applications of this approach. Besides the identification of objectives (both from clean and noisy data), the method can be used for the construction of surrogate models for expensive MOPs (e.g., MOPs with PDE constraints), which can yield significant speed-ups.

3 - PDE-Constrained Multiobjective Optimization by Reduced-Order Modelling
Stefan Volkwein

In the talk multiobjective optimization problems governed by partial differential equations are considered. The goal is to compute numerically Pareto optimal points for the underlying optimization problem. After discussing analytical aspects numerical solution methods are presented which utilize reduced-order modeling. A-posteriori error analysis ensures a desired accuracy for the Pareto optimal points. Numerical example illustrate the theoretical findings and numerical solution approach. The presented work is partially supported by the DFG-SPP 1962.

4 - Dynamic Optimisation of Aiming Strategies in Solar Power Tower Plants
Thomas Ashley, Emilio Carrizosa, Enrique Fernández-Cara

Research into renewable energy sources has continued to increase in recent years, and in particular the research and application of solar energy systems. Concentrated Solar Power (CSP) used by a Solar Power Tower (SPT) plant is one technology that continues to be a promising research topic for advancement. The distribution of temperature on an SPT plant receiver directly affects the lifespan of the structure and energy generated by the plant. Temperature peaks and uneven distributions can be caused by the aiming strategy enforced on the heliostat field. A non-optimised aiming strategy can lead to suboptimal energy generation and, more importantly, to risk of permanent damage to receiver components from thermal overloading due to sharp flux gradients. In this work, previous work on a continuous optimised aiming strategy is extended to consider a dynamic case, where the maximisation of energy gained whilst maintaining a homogeneous flux distribution on the receiver is considered as a bi-objective of the problem. Two dynamic constraints are then considered, which relate to physical limitation of the SPT plant due to the change in solar conditions with time. Two algorithms are developed; penalisation and augmented Lagrangian, in order to solve the problem. An illustrative example is presented for a real-world SPT plant.

■ TC-16

Tuesday, 12:30-14:00 - Theatre A

Vehicle Routing I

Stream: Combinatorial Optimization II
Invited session
Chair: Francesca Vocaturo

1 - Exact and Heuristic Algorithms for the Carrier-Vehicle Traveling Salesman Problem
Gunes Erdogan, E. Alper Yildirim

In this paper, we focus on the Carrier-Vehicle Traveling Salesman Problem (CVTSP) that arises in a multi-vehicle system consisting of a slow but large vehicle, referred to as the Carrier (e.g., a ship), with a virtually unlimited operational capability, and a faster but smaller vehicle, referred to as the Vehicle, with a limited operational capability (e.g., a helicopter or an unmanned aerial vehicle). The Carrier is capable of transporting, deploying, recovering, and servicing the Vehicle. The CVTSP is concerned with the problem of planning and coordinating the routes of the Carrier and the Vehicle in such a way that all of the target points are visited by the Vehicle in minimum total time starting from an origin and ending at a destination point. We identify several structural properties of the CVTSP, based on which, we present a mixed integer second order conic optimisation model for the CVTSP, as well as an Iterated Local Search (ILS) algorithm. We report the results of our computational experiments with the model and the algorithm on instances from the literature.

2 - Collecting manures from local farms for a biogas plant in Norway
Arild Hoff, Brit Flemmen Berg, Urooj Pasha

A rich real-world routing problem for a planned biogas plant in Norway is studied. This plant will produce output as energy and decomposing residue from organic fertilizers and sewage sludge. Hence, transportation of manure from nearby farms and sewage from other installations is essential for providing the necessary raw materials for the plant. The decomposed residue should be transported back to the farms and used as fertilizers. Hence, the problem will include both pickup and delivery demands, but since the products cannot be mixed, the routing must be planned as a backhaul problem performing all deliveries before the pickups can take place. The problem can be classified as an inventory routing problem with inventory constraints both at the plant and at the individual farms or eventually a cluster of farms. In addition, there are decisions regarding the appropriate composition of the vehicle fleet, the frequency of visits at the individual farms and the routing of the vehicles over a given time period. Another constraint is some roads that might not be accessible all around the year, making some visits possible only in the summer season. We will present a mathematical model to describe the problem and exact solutions of small instances will be reported along with a heuristic method for solving the real-life problem with real data.

3 - Adaptive dispatching policy for dynamic vehicle routing: a supervised-learning approach
Emanuele Manni, Gianpaolo Ghiani, Andrea Manni

This paper deals with the dynamic Pickup and Delivery Problem, in which a fleet of vehicles must service a set of customer requests characterized by a pickup and a delivery location, as well as by a priority class. The goal is to maximize the overall quality of service provided to the customers. Two classes of policies are common in the literature, namely reactive and anticipatory policies, both of them having pros and cons. In our contribution, we propose a new dispatching policy with a twofold goal. First, we aim to trade off and obtain performance matching the quality of anticipatory algorithms with a computational effort similar to that of reactive approaches (typically, the interarrival time between two consecutive requests can be as little as a few seconds). Our second goal is to achieve scalable performances, meant as the ability to easily deal with instances of increasing size. The basic idea of our policy is to reserve a fraction of the fleet capacity to the top prior classes that deserve to be serviced as soon as possible. In addition, our dispatching policy is parameterized and the optimal parameter setting is constantly updated over time as soon as new customer requests arrive. In particular, at each time step the parameter values are predicted by means of a supervised-learning model, suitably trained off-line on a sample of the instance population. Computational results on randomly-generated instances of varying size certify the quality of the proposed approach.

4 - A Solution Strategy for the Delivery Problem in Postal Service Companies
Francesca Vocaturo, Demetrio Laganà, Gilbert Laporte

We deal with a delivery problem that can be modelled and solved as a dynamic multi-period general routing problem. In particular, the items that must be delivered to specified recipients are represented by letter post, parcel post, etc. These items dynamically reveal themselves over time, i.e., over a planning horizon consisting of several days. We distinguish between the items to be handed by assigning them a priority label (e.g., 24-hour express postal services are classified as urgent). The problem consists of defining, day by day, the items that must be delivered and the related routes, with the aim of minimizing the total routing cost over the planning horizon. A fleet of homogeneous vehicles is used in the delivery activity and priorities are met. In order to tackle this delivery problem, we propose a heuristic algorithm based on adaptive large neighbourhood search. Computational results show the effectiveness of our solution strategy.

■ TC-17

Tuesday, 12:30-14:00 - A005

Decision making in energy policy problems

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: Cristian Pelizzari

1 - Impacts of Nuclear Project Delays on Turkey's Emission Projections: A Bottom-Up Modeling Approach
Danial EsmaeiliAliabadi, Murat Kaya

Turkey has been planning to harness nuclear energy since the 70s; nonetheless, it was only in 2010 that the first plant project was initiated. As of 2018, two nuclear power plant projects with a total installed capacity of 9.28 GW are progressing in different development and construction phases. However, similar to most nuclear plant projects worldwide, these projects have been delayed multiple times due to a host of reasons. In this study, we aim to quantify the effects of such delays on carbon emission projections of Turkey, based on a number of project delay scenarios. In particular, we discuss if the country will be able to meet her National Determined Contributions (NDC) towards emissions reduction. To this end, we utilize a detailed bottom-up model of the country's energy system that we developed. The model predicts the annual energy mix of Turkey until a given horizon, taking into account supply, demand, technology and policy predictions.

2 - A steady-state game of a net-zero emission climate regime
Olivier Bahn, Alain Haurie

In this presentation, we propose a very simple steady-state game model that represents schematically interactions between coalitions of countries in achieving a necessary net-zero emission of greenhouse gases in order to stabilize climate over the long term. We start from a situation where m coalitions exist and behave as m players in a game of sharing a global emission budget that can only be maintained by negative emission activities. We compare a fully cooperative solution with a Nash equilibrium solution implemented through an international emission trading scheme. We characterize the fully cooperative and Nash equilibrium solutions for this game in a deterministic context and provide a numerical illustration.

3 - Cross-sectional coherent forecasts for electric energy consumption in Brazil
Erick Meira de Oliveira, Fernando Luiz Cyrino Oliveira, Fotios Petropoulos, Jooyoung Jeon

Brazil's energy consumption and generation have risen rapidly in recent decades, lifting its world ranking to the eighth largest energy consumer and tenth largest producer in 2018. Even so, Brazil's electricity supply system has shown to be vulnerable to electricity shortages and has demanded significant overhaul in order to address its challenges. In this context, accurate estimation of energy consumption is of paramount importance for policy makers, especially in terms of complementary sources, since the maximum capacity of Brazilian hydroelectric generation is close to being achieved. In this work, a hybrid, optimal reconciliation approach is proposed to estimate and subsequently forecast electric energy consumption in Brazil at both total and disaggregated levels. The approach combines Bootstrap Aggregating (Bagging) algorithms and hierarchical time series methods to obtain highly accurate forecasts of electric energy demand in Brazil. The obtained results attest that the proposed methodologies can substantially improve forecast accuracy. Findings and policy implications are further discussed.

4 - The Optimal Number of Allowances in an ETS: A Bilevel Stochastic Programming Approach
Cristian Pelizzari, Paolo Falbo, Giorgio Rizzini

The third phase of the European Union Emissions Trading System, EU-ETS, is almost ending and decisions have already been taken for the fourth phase, from 2021 to 2030. In line with the 2030 Climate & Energy Framework, the system has undergone some crucial modifications of its rules. In particular, the overall number of EU-ETS allowances will decrease by 2.2% per year from 2021 onwards, while the current annual reduction rate is 1.74%. The key variable of the present model is the number of emission allowances to be issued by the regulatory authority. We assume that the price of emission allowances is linked to the probability that total emissions of diverse economic players will exceed the cap. So, restricting the number of allowances issued in an ETS increases their price, raising consequently production costs and lowering the competitiveness of an economic system. On the contrary, a large number of allowances can lower their price so close to zero to vanish their impact. A bilevel stochastic programming model is advanced, where the regulatory authority trades-off economic growth with environmental targets, influencing the choices of electricity producers (switching between polluting and renewable plants) by means of the number of emission allowances to be issued. The generation of scenarios mixes qualitative and probabilistic methods. In particular, Markov chain bootstrapping methods are used to jointly simulate gas and coal prices and electricity demand.

■ TC-18

Tuesday, 12:30-14:00 - C112

Design of Experiments, and OR in Quality Management

Stream: OR in Quality Management
Invited session
Chair: Jose Nunez Ares

1 - OR techniques applied to Design of Experiments. Overview and an example on enumerating Response Surface Designs using integer programming and high-throughput computing
Jose Nunez Ares, Peter Goos, Jeff Linderoth

Gaining competitive advantage requires today's businesses and industries to innovate and improve at an increasing speed. Modern products, production processes and services are more complex than ever, so optimizing product formulations or compositions, production process settings and services requires solving high-dimensional decision problems. An important management science tool to cope with this task is design of experiments. An experimental design is a plan to systematically explore alternative product formulations/compositions, process settings or service offerings, identify the factors that drive their performance/quality, and determine the optimal settings for these factors. A practitioner desires the best experimental plan for the experimental conditions at hand. This optimization nature of Design of Experiments has given rise to much research involving optimization techniques, both continuous and discrete. This talk is divided in two parts. First, we will give an introduction to design of experiments, outlining the connections with optimization techniques and giving the most relevant references. Second, we will present an application on enumerating Response Surface Designs using integer programming and high-throughput computing.

2 - A mixed integer programming approach for analyzing screening experiments
Alan Vazquez, Eric Schoen, Peter Goos

The first stages of product and process development involve screening experiments to identify, from a list of potentially influential factors, those that are indeed influential. Screening experiments are commonly carried out using screening designs such as fractional factorial designs, Plackett-Burman designs and definitive screening designs. After completing the tests of a screening design, the response of the screening experiment is linked to the factors through a statistical model, which may include main effects, interaction effects or quadratic effects. Finding a suitable statistical model involves searching among all possible models that can explain the data and identifying the model that includes the most influential factors' effects.

For screening experiments involving many factors, it is computationally infeasible to enumerate and evaluate all possible models. To adress this issue, we introduce a mixed integer programming (MIP) approach for analyzing data from screening designs. Our MIP approach avoids enumerating all possible models and allows to include subject-matter expertise in the model search, through the inclusion of linear constraints in the mixed integer program. Using real-life examples, we illustrate the potential of our MIP approach for analyzing data from screening designs and demonstrate its advantages when compared to the benchmark methods available in the literature.

3 - Modeling Time Dependence of Arrivals for Process Quality Assessment
Petra Tomanova

Precise estimates of times between arrivals is a key aspect of process simulations; subsequently, process optimization and process quality assessment. Times between arrivals typically exhibit strong autocorrelation structure. Even after seasonal and diurnal adjustment, arrivals still tend to cluster over time. In order to predict more accurate values, we utilize a broad class of autoregressive conditional duration models and their generalization to generalized autoregressive score models. Once the process of arrivals is estimated, a process quality assessment can be performed using process simulations. The empirical study of an online bookshop in Prague, Czech Republic shows the importance of the correct treatment of the time dependence of arrivals and how process simulations based on standard models assuming exponential distribution with a constant rate might lead to suboptimal decisions.

4 - Root Cause Analysis in Manufacturing - A Time-Sensitive Approach
Eduardo e Oliveira, José Borges, Vera Miguéis

Root Cause Analysis (RCA) is a crucial process for companies to achieve continuous improvement. It focuses on finding the true cause of a problem, in order to correct it and avoid future occurrences of the same problem.

In this work, we define the manufacturing RCA problem, identifying its elements (e.g., Products, Equipment) and their relations. In addition, we establish a framework on the types of data that can be available to characterize this type of problem: Location-Time, Physical, and Action-Log. We then present an approach to manufacturing RCA problems with data of the type Location-Time, which are the most commonly available. This approach adds to the existing literature by considering the fact that root causes change over time - i.e., there is concept drift. In order to deal with this issue, we develop a method that identifies periods with problems, and analyzes each of these periods individually.

In addition, we develop an approach for RCA in problems that, in addition to the Location-Time data, uses Physical data. This approach is based on one-class classifier, which makes use of Kernel Density Estimation to model normal products.

The developed approaches are evaluated in a case study scenario from the semiconductor manufacturing industry.

■ TC-19

Tuesday, 12:30-14:00 - C115

Portfolio Optimization I

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: Wlodzimierz Ogryczak
Chair: Ana Garcia-Bernabeu

1 - The Generalized Little's Law and an Asset Picking System to Model and Maintain a Customized Investment Portfolio: from a Prototype to a Large-Scale Model
Maria Luisa Ceprini, John D C Little

So far our research remains the only application of Little's Law in finance and financial engineering fields. In the first part we created an Asset Picking System (APS) structure that, combined with Little's Law (LL), Little's Law.2, shaped by two theorems and three corollaries (LL.2), and Generalized Little's Law (GLL), generates the GLL-APS model, a financial engineering tool bridging operational research and finance. In the first part of the project we run a simple prototype with only one customer for checking its basic working assumptions. The right prototype working, supported by the results, gave us a strong stimulus to focus on key topics to introduce in the model during this final step of the project. We were conscious of the long list waiting to be settled. Eventually, we figure out an answer for each of them allowing us to test the GLL-APS model with more advisers, customers and assets from the global market, and plan an orderly rollout of the model in multiple sectors, from financial institution to industry and university. Last, but not the least, the flexible structure of a well-defined multi-use building model, underlines on the crucial node between Theory and Practice.

2 - Multi-objective evolutionary algorithms for tri-criterion mean-variance-sustainable portfolio management
Adolfo Hilario, Ana Garcia-Bernabeu, José-Vicente Salcedo, David Pla-Santamaria

In recent years sustainable investing, which is an approach that considers environmental, social and governance (ESG) factors in portfolio selection and management has become a mainstream investment practice. Despite the widespread use of the classical bi-criteria Markowitz's mean-variance (MV) framework, a broad consensus is emerging on the need to include more criteria in the portfolio selection decision process. Some scholars have attempted to include sustainability as a third criterion to reflect the individual preferences of socially responsible investors who aim for strong financial performance but also believe that their investments should provide important societal benefits.

Multiobjective Evolutionary Algorithms (MOEAs) have been recently used for portfolio selection, thus extending the (MV) methodology to obtain a mean-variance-sustainable nondominated 3D pareto front. Authors have applied an elitist MOEA based on the concept of ϵ-dominance called ev-MOGA. It tries to ensure convergence towards to the pareto set in a smart distributed manner along the pareto front with limited memory resources. This algorithm also adjusts the limits of the pareto front dynamically and prevents the solutions belonging to the ends of the front from being lost. Moreover, the individual preferences of socially responsible investors could be considered using a novel tool known as Level Diagrams which helps the investor to better understand the range of values attainable.

3 - CVaR-Based Ratio Measures for Enhanced Index Tracking
Wlodzimierz Ogryczak, Gianfranco Guastaroba, Renata Mansini, M. Grazia Speranza

In recent years, shortfall or quantile risk measures have been playing a central role in financial applications. The Conditional Value-at-Risk (CVaR) is one of such measures. The Enhanced Index Tracking Problem (EITP) calls for the determination of an optimal portfolio of assets with the bi-objective of maximizing the excess return of the portfolio above a benchmark and, simultaneously, minimizing the tracking error. In this paper, we formulate the Enhanced Index Tracking Problem based on using Weighted CVaR (WCVaR) measures, which are defined as combinations of a few CVaR measures thus allowing a more detailed risk aversion modeling while preserving the simplicity of the CVaR. More precisely, we use the weighted conditional drawdown measure, corresponding to the WCVaR, to formulate the problem as a class of risk-reward ratio optimization models which, using standard linearization techniques, can be reformulated in terms of LP solvable models. The application of the WCVaR to the EITP is analyzed, both theoretically and empirically. Through extensive computational experiments, the performance of the optimal portfolios selected by means of the proposed optimization models is compared, both in-sample and, more importantly, out-of-sample, to the one of the portfolios obtained using another recent optimization model taken from the literature.

■ TC-20
Tuesday, 12:30-14:00 - C006

Business Analytics III

Stream: Business Analytics
Invited session
Chair: Dries Benoit
Chair: *Kristof Coussement*

1 - Business Analytics Capability, Organisational Value and Competitive Advantage
Michael ONeill

Business Analytics makes the assumption that given a sufficient set of analytics capabilities exist within an organisation, the existence of these capabilities will result in the generation of organisational value and competitive advantage. Taken further, do enhanced capability levels lead to enhanced impact for organisations? Capability in this study is grounded in the four pillars of Governance, Culture, Technology and People from the Cosic, Shanks and Maynard capability framework. We set out to undertake the first empirical investigation to measure if there is a positive relationship between Business Analytics capability levels as defined by Cosic, Shanks and Maynard, and the generation of value and competitive advantage for organisations, and do enhanced capability levels lead to enhanced impact. Data gathered from a survey of 64 senior analytics professionals from 17 sectors provides evidence to support that a strong and statistically significant correlation exists between higher capability levels and the ability to generate enhanced organisational value and competitive advantage.

2 - The Impact of Local Competition on WOM
Matthijs Meire

Social media, and customer reviews in specific, have attracted large academic interest over the last decade. Although this resulted in a broadened understanding in the relationship between customer reviews and sales, company reviews are still largely evaluated in isolation from other companies' reviews. To this end, we propose to include not only dynamics between reviewers, but also local company neighborhood dynamics. Indeed, the company operates in a competitive local landscape, in which other company ratings can influence the focal company ratings. We define several neighborhoods of restaurants using the online review site Yelp, and collect the corresponding reviews for the entire neighborhood. Preliminary results show that there are indeed significant effects from local competition. Moreover, we propose to use a dynamic model that performs significantly better compared to static models previously used in the literature for similar problems. Our results suggest that companies should be aware that the entire neighborhood of the companies influence their own customer reviews.

3 - Home Location Prediction Using CDR Data
Dieter Oosterlinck, Dries Benoit, Philippe Baecke

This research aims to investigate the value of Call Detail Record (CDR) data in predicting locations of interest. In this research, the predicted location of interest is the home location. Previous research mainly focuses on social media data when predicting home location (e.g. Twitter data with locations tags). CDR data also enables to construct the social network of the individuals. We therefore investigate the added value of including location data of the social network, as opposed to using only the location tags of the individual. On a methodological level, we also investigate the use of techniques that take advantage of the relation between the longitude and latitude of the geo tags.

■ TC-21
Tuesday, 12:30-14:00 - F101

Lot Sizing VII - Lot-sizing with applications

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: Herbert Meyr

1 - Dynamic lot sizing for liquid inventories
Onur Kilic

We study a dynamic lot sizing problem for liquid inventories subject to deterioration (e.g., fuels and other industrial fluids). The system has a single inventory point (i.e., a storage tank) where successive lots of the product are stored over time. There are two suppliers which offer different levels of quality and price, as well as fixed ordering costs. To satisfy demand, the quality should meet a minimum level. The product perpetually deteriorates over time, yet it is also possible to upgrade or downgrade its quality by mixing the available inventory with a new lot of higher or lower quality. The quality of a mixture is the weighted average of the quality of the loads mixed. The problem is to find a minimum-cost replenishment plan satisfying all demands over a finite planning horizon. We provide two formulations of the problem: a mixed integer non-linear model and a mixed integer linear model where non-linear expressions are linearized by means of a radix-based discretization scheme. These models can be directly fed into available solvers, but they are computationally expensive to be implemented in practice. To that end, we develop two efficient heuristics where we focus on classes of feasible solutions which can be obtained in polynomial-time. We numerically illustrate that our heuristics can provide high-quality solutions in very short computational times.

2 - Product line selection in the fast-moving consumer goods industry

Xavier Andrade, Luis Guimarães, Gonçalo Figueira

Currently, the fast-moving consumer goods industry is characterized by its large assortments. This results from fierce competition and the struggle from manufacturers to attain market share. Adversely, this is a capital-intensive sector where economies of scale are a priority. Setups in this industry are expensive as, besides the direct cost, the opportunity cost from the capacity loss must be accounted for.

The decision of which products to offer in a given planning horizon is of a strategic nature, but its implications heavily affect lower-level decisions. This means production planning needs to be looked at with a smaller granularity than the product line and sales decision. The selection of products to offer greatly affects manufacturing complexity costs. Besides the development and administrative costs associated with a product, machines need to be setup for producing it, implying additional costs and a production time loss. Moreover, production run length changes to accommodate the selection and manage the tradeoff between setups and inventory.

We develop a mixed integer linear program integrating the multiperiod capacitated lot sizing problem with revenue management, considering fixed costs and a attraction model for demand. Additionally, we incorporate safety stock constraints into the linear model. We assess the value of considering multiple periods and safety stock, and analyze different levels of coordination between marketing and production.

3 - Perishability in integrated procurement and reprocessing planning of reusable medical devices in hospitals

Steffen Rickers, Florian Sahling

We present a new model formulation for a multi-product dynamic order quantity problem with product returns and a reprocessing option for medical devices. The model considers the limited shelf life of sterile medical devices as well as capacity constraints of reprocessing and sterilization resources. The time-varying demand is known in advance and must be satisfied by either procuring new medical devices and/or by reprocessing used and expired ones. The objective is to determine a feasible procurement and reprocessing schedule that minimizes the incurred costs. As already for small problem instances the optimal solution cannot be determined in reasonable time, we present a construction heuristic and an improvement heuristic.

4 - Modeling and solving a setup and cutting problem of label printing industry

Herbert Meyr

The talk is motivated by a real world application in the label printing industry. The printing company's customers are consumer goods manufacturers. They typically require labels of several sorts of a single product family like, for example, different sorts of yogurt. These labels show different imprints, but share the same form and size. Thus, from the printing company's point of view, a customer order comprises several order lines with varying demands for different sorts, which have to be delivered together in a batch. The printer can print several printing lanes of equal width in parallel on a single roll of paper of sufficient length. The maximum number L of lanes is pre-defined.

To set up the printer, a printing plate has to be designed incurring fixed costs. Up to L different sorts can be printed in parallel. However, if their demands are unequal, surplus quantities are generated. These surplus quantities cannot be stored, but need to be disposed as scrap. Each unit of scrap causes variable costs. Thus the planning problem arises how to assign the sorts to and spread their demands over the lanes of different printing plates so that the sum of setup costs for the plates and variable costs of surplus scrap are minimized.

We formulate this problem as a simplified General Lotsizing and Scheduling Problem for Parallel Production Lines (GLSPPL), propose a decomposition heuristic based on Dynamic Programming and present numerical results.

■ TC-22

Tuesday, 12:30-14:00 - F102

Reverse Logistics

Stream: Sustainable Supply Chains
Invited session
Chair: Kaveri Kala

1 - Warranty Matching in a Consumer Electronics Closed-Loop Supply Chain

Stef Lemmens, Andre Calmon, Stephen Graves

We introduce and analyze an assignment problem that occurs in Closed-Loop Supply Chains (CLSCs). We consider a CLSC with three players: an Original Equipment Manufacturer (OEM) that produces electronic devices, a Wireless Service Provider (WSP) that sells the devices manufactured by the OEM and offers warranties to customers, and customers that purchase and use these devices and file a warranty claim when the device fails. In this CLSC, there are two warranties in place: (a) the customer warranty, offered by the retailer to the customer, and (b) the OEM warranty, provided by the OEM to the retailer. In WSP's case, the customer warranty guarantees an immediate replacement of the faulty device with a working one, while the OEM warranty requires WSP to wait for the device repair, such that a replacement device is not sent immediately to WSP. Ideally, WSP wants all device-customer pairs to have matched warranties: that is, the warranties are matched when the remaining time on the customer warranty is the same as the OEM warranty on the device. If the customer has less time left in its customer warranty than the device has left in the OEM warranty, then we denote the uncovered time as the time difference between the end of the OEM warranty and the end of the customer warranty. We propose three matching policies and compare their performance with WSP's current practice. Our results show that these three matching policies can reduce the uncovered time by about 80 %.

2 - A New Model to Design and Improve a Reverse Logistics Network

Saman Hassanzadeh Amin, Babak Mohamadpour Tosarkani

A new mathematical model for a reverse logistics network configuration is introduced in this talk. In this research, a scenario-based possibilistic model and the solution approach are described. The solution approach can handle the uncertainty in the parameters. In addition, the optimization model is extended to a multi-objective model.

3 - Multi-objective Reverse Logistics Network Design

Vipin B, Manish Shukla, Raghu Sengupta

Reverse logistics, due to the potential benefit to the producer by carrying out a set of activities resulting in value recovery from end-of-life and end-of-use products while complying with environmental regulations, has gained interest among researchers (Alumur et al., 2012; Govindan et al., 2015). One of the major concerns in reverse logistics network design is the trade-off between maximizing profit and minimizing the environmental impact. In this research, we propose a multi-objective reverse logistics network design model which captures the dynamic nature of demand for a variety of products. The proposed mixed-integer linear programming model addresses the conflicting objectives of maximizing profit and minimizing carbon emission. We compare the results of our model with the findings from Yu and Solvang (2018). Several managerial insights are derived based on our analysis under different market scenarios.

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4 - Analysis of Citizen Response and Incentives for Waste Management

Kaveri Kala, Nomesh Bolia

Segregation is regarded as the first and one of the most critical steps for effective waste management. Further, in developing countries, about 70 percent of the urban waste generated is bio-degradable. Thus, composting becomes an important waste processing technique. Large scale segregation and composting involve collection, transportation and other logistics that necessarily lead to huge inefficiencies. A more sustainable approach is first segregation at source and then decentralized composting at the level of households or residential colonies. In present study the primary data is collected through a survey and analysed using SPSS. Further, Logistic Regression is used to develop four models. The first two models attempt to generate insights and analyze the variation in people's behaviour to segregate/compost with respect to their socio-economic categories. The other two models, based on Multinomial Logistic Regression (MLR), consider interventions to cause a change in people's behavior to analyze if the chosen interventions can make people segregate/compost waste, and if yes, the variation in this change with respect to their socio-economic category. The results and their implications lead to sharp insights on the functioning of the waste management ecosystem and also suggest direct action items. These insights and action items can eventually help the decision makers in formulation and implementation of better Solid Waste Management (SWM) policies.

■ TC-23

Tuesday, 12:30-14:00 - F103

Order Fulfillment and Last-Mile Delivery

Stream: Demand and Supply Management in Retail and Consumer Goods

Invited session

Chair: *Alexander Hübner*

1 - Anticipative Dynamic Slotting for Attended Deliveries

Catherine Cleophas, Magdalena Lang, Jan Fabian Ehmke

Attended home deliveries are both a driver and a symptom of the e-commerce evolution. When customers have to attend the delivery, retailers and customers need to agree on delivery time slots at the time of the order. Because not all time slots are equally popular with customers, wasteful idle times result when aiming to deliver during each customer's preferred time. Order characteristics as location, basket value, and time slot determine the efficiency of vehicle routes and profitability of accepted orders. Therefore, current research advises dynamic slotting, offering only those time slots to individual customers that optimise expected profitability. In this contribution, we introduce and compare dynamic slotting approaches to exploit the potential of customer's time slot choice behaviour and implications for delivery resources. We introduce approximate dynamic programming approaches that rely on anticipative information. Demand forecasts support preparing such information before the start of the order horizon to support fast but informed decisions. On request arrival, we enable fast checks for the feasibility of time slots as well as fast immediate evaluation of the effect on final delivery schedules and future acceptable orders. Thereby, we offer an option towards complex anticipation of final routing schedules. Moreover, we inform about the value of anticipative information by looking at alternative approaches and demand scenarios.

2 - Predictive Routing for the Meal Delivery Routing Problem

Alexander Hess, Stefan Spinler, Matthias Winkenbach

Meal delivery has become an omnipresent phenomenon in urban logistics in recent years with the launch of companies like Delivery Hero, Deliveroo, Grubhub, UBER Eats, and many others. While their business models and relationships with the couriers differ (freelance / sharing economy platform vs. employees), the underlying scheduling and routing problem is the same. We extend the recent literature by analyzing the effects of different scheduling policies (e.g., stacking of orders) and show how real-time demand forecasts may be employed to enable predictive routing.

3 - A bi-objective adaptive large neighborhood search to facilitate a reduction in food waste during e-grocery deliveries

Christian Fikar

Motivated by urban e-grocery deliveries, this work introduces an adaptive large neighborhood search to assist a reduction in food waste during delivery processes. A bi-objective problem setting is considered aiming to jointly minimize travel distances and food quality losses resulting from delivery and loading processes. A store-based delivery setting is studied, i.e., orders are picked up from stores and subsequently delivered to customers' premises. The problem setting is modelled as a pickup and delivery problem, however, the procedure additionally needs to decide on where to pick up products based on current stock levels and expected quality of items at delivery. Therefore, food quality models are integrated to estimate remaining shelf lives throughout delivery operations. Results of computational experiments indicate a substantial trade-off between minimizing travel distances and food waste, highlighting the importance of tailored solution procedures to facilitate sustainable operations in the future.

4 - Optimization for the Delivery of Service Differentiation Through Operating Segments: Design and Control Challenges

Morris A. Cohen, Jose Guajardo

This paper presents a model hierarchy for developing an optimal differentiation strategy for the delivery of services. It is based on the framework introduced in Guajardo and Cohen [2018] for the management of value-added services that are bundled with manufactured products, (aka servicization). The model utilizes the concept of operating segments (introduced by Frei and Morriss [2012]) and considers the definition of market segments appropriate for differentiated services and the design of such services as well as the infrastructure required to produce them. The model integrates these design decisions with policies for the management of the operational processes required to deliver differentiated service products to multiple market segments. The model formulation incorporates tradeoffs, risks and constraints associated with decisions at all levels in the planning and control hierarchy and considers their interactions. A specific instance of the model framework is developed for the case of after-sales services in order to illustrate the model and its potential for application. Modeling, solution and implementation challenges are considered.

■ TC-24

Tuesday, 12:30-14:00 - F103A

Various aspects of SCM

Stream: Supply Chain Management
Invited session
Chair: Patrick Rigot-Muller

1 - Comparison of Public Procurement systems in two countries Using Stakeholder Theory
Paul Davis

The public procurement process of any country is based on the principle of achieving better value for money. This is to say, proper planning, selection, and awarding of contracts must be given based on financial or economic considerations. Public procurement has been tipped to be a key factor particularly in stimulating economic growth. As a result, countries are thus obliged not only to identify the suitable procurement method that suits their needs but also one that guarantees maximum benefits of the award outcomes.There are two prevailing procurement award criteria acquisition based on the lowest price criterion or through the most economically advantageous tender criterion. Therefore, considering that each system aims at providing the best value for money, this study will empirically examine which of the beforementioned systems works best towards achieving its intended objectives. However, through in-depth multiple case studies, we reframe and explore how award criteria works under different economic, political, legal, context and at the same time read deeper into the outcomes that both approaches have resulted in the Irish and Saudi Arabia regimes respectively.

2 - The Impact of Mass Customisation Capability on Operational Performance Measures
Ali Nazarpour

The aim of this research is to explore how different levels of Mass Customisation Capability (MCC) impact different levels of operational performance. The mass customisation literature debates on the impact of MCC on operational performance measures of quality, delivery, flexibility and cost. Using the cumulative capabilities perspective (the sand cone model), we intend to build on previous findings and further examine the relationships between mass customisation development levels of manufacturing plants and their operational performance levels. In particular, this study asks the following research question: RQ. What is the impact of MCC on different types of operational performance measures? In doing so, this study uses survey data from Fifth round of Global Manufacturing Research Group. We categorise manufacturing plants based on their MCC levels, namely: high MCC, medium MCC and low MCC. Subsequently, we run three models to examine impact of different levels of MCC on quality, delivery, flexibility and cost. Our preliminary analysis indicates that at certain levels of MCC, manufacturing plants can simultaneously achieve high levels of quality, delivery, flexibility and cost. This means that MCC levels can be used as predictors of operational performance measures. The findings of this study have important implications for both academic and practitioner's communities.

3 - Examing the effect of enviornmental subsidies on capacity allocation in the Irish RoPax market: A game theoretic approach
Eamonn O'Connor

Improved sustainability of freight transport is a stated objective of the European Union's TenT programme. The promotion of initiatives to facilitate modal shift from road to short sea shipping has been a key mechanism by which the commission has sought to achieve this objective. Support for initiatives in the form of funding calls have come in the form of supply side subsidies. There is scrutiny however to the effectiveness of these initiatives. This has led to a call for demand side interventions that give incentives directly to the shipper as the customer. This paper explores this topic through examining the potential effect of alternate demand and supply side initiatives to facilitate a modal shift on a specific route connecting Ireland to the continent. Namely, the paper examines the effect of an eco-bonus on capacity allocation on the Ireland-France RoPax route to facilitate a modal shift from the less environmentally sustainably route through the UK. To achieve this the paper applies a well-established oligopolistic game theory model to examine strategic behaviour of existing service providers in competitive environments. The findings provide ex-ante evidence to policy makers regarding the potential effectiveness of alternative initiatives to promote modal shift in a competitive market setting.

4 - Conciliating sales and operations perceptions in supply chain risk management: a case study with a tier-2 supplier in the automotive sector
Patrick Rigot-Muller

The automotive sector is particularly sensitive to disruptions in supply chains, due to just-in-time policies and the complexity of upstream supply chains. When conducting studies aimed at reducing supply chain risks, one of the challenges is to conciliate the production and the sales perceptions of risks criticalities. While operations tend to look at expected production loss, sales will also consider the product criticality, delivery times and reputational aspects. In this research work, the author analyses the global supply chain of a chemical company, tier-2 supplier in the automotive sector. The business unit analysed is a world leader with a global market share of nearly 60%. It has nine production sites in North America, South America, Europe and Asia. This study aimed at conciliating production and sales perceptions of criticality, via the identification of about 200 flows (defined by a product, a client and a production plant), which were scored based on the Production and the Business criticalities. Data and variables were defined and collected with managers. Resulting flows, plotted in an Operations vs Business matrix, were used to prioritise improvement actions.

■ TC-25

Tuesday, 12:30-14:00 - F104

Reliability and Maintenance

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: Aikaterini Faidra Sevastidou

1 - Log-based predictive maintenance in discrete parts manufacturing
Clemens Gutschi, Nikolaus Furian, Dietmar Neubacher

The performance of discrete parts manufacturing systems is heavily influenced by unplanned machine breakdowns. Predictive maintenance allows for the conversation of unplanned machine breakdowns to scheduled corrective maintenance actions. We present a data-driven log-based approach for estimating the probability of machine breakdowns during specified time intervals in the future. Machine learning algorithms are utilized for a specific use-case which is based on real-world data-sets including machine log messages, event logs and operational information. We will present an overview on predictive maintenance strategies as well as applied data-preparation, feature-engineering and machine learning methods for estimating the remaining useful lifetime. The comparison of two different methods for RUL-estimation is indicating that machine failures can be predicted up to 168 hours in advance with promising precision and hit-rate.

2 - Robot Prognostics based on reliability analysis and RUL estimation using an iterative methodology
Francesco Aggogeri, Angelo Merlo, Claudio Taesi, Nicola Pellegrini

The aim is to present an iterative methodology to evaluate robotic system reliability and Remaining Useful Life (RUL) integrating FMECA (Failure Modes, Effects and Criticality Analysis), life data analysis, and data-driven & model-based methods. Starting from the FMECA analysis, the methodology proposes to identify the main critical components of new parts or systems using life data analysis. A database collects and shares data directly from the field on similar systems and applications. The data gathered are stored and managed via a web-based interface, the user may obtain them in real time as needed, when a modification in the robot or production cells occurs. Information are captured through a set of appropriate sensors, selected and located studying historical data. From this dataset, RUL of components may be estimated using data-driven methods or model-based approaches. The RUL results need to be shared with ERP systems to optimize production resources and maintenance activities and with FMECA again, to optimize new projects in a closed loop. This work presents a preliminary application of the methodology. An anthropomorphic robot has been considered to be integrated in a production cell. This research is a part of PROGRAMS: PROGnostics based Reliability Analysis for Maintenance Scheduling, H2020-FOF-09-2017-767287.

3 - Condition-based production and maintenance for multi-unit systems

Michiel uit het Broek

Many multi-unit systems face significant economic dependencies for maintenance, e.g., expensive vessels are needed to perform maintenance at offshore wind farms. It is often cost efficient to cluster maintenance for several units. However, when maintenance for units with different degradations levels is clustered, then maintenance is performed too early for the low deteriorated ones or too late for the highly deteriorated ones. In such situations, an interesting question is whether it can be profitable to adjust the production rates in order to synchronize the deterioration processes for the different units.

The current maintenance literature typically assumes that machines always produce at a fixed production rate and that we cannot influence the deterioration rate. However, there are many real-life situations where we can adjust the production rate for machines. The deterioration rate of these systems typically depends on the production rate, implying that the deterioration process can be controlled by adjusting the production rate. The applies, for instance, to wind turbine gearboxes and generates that deterioration faster at higher speeds.

We study a multi-unit system with condition monitoring and economic dependencies. We are interested in the structure of the optimal policy, i.e., when to adjust the production rate of a unit in order to postpone or advance its maintenance moment to improve the efficiency of clustering.

4 - A Monte Carlo Based Approach for Simultaneous Scheduling of Production and Maintenance in a Logistics Context

Aikaterini Faidra Sevastidou, Charis Marentakis, Dimitrios Emiris

Production scheduling and maintenance planning are two interdependent operations that often are treated independently when planning, although both affect the manufacturing process. This works examines the integration between production and maintenance processes in a failure-prone manufacturing system and proposes an integrated decision model that combines preventive maintenance decisions and production scheduling. The key objective is to maximize the system's manufacturing capacity as a function of the overall operational reliability level of the system. Assumptions on available resources and machine degradation have been made. The decision model is naturally formulated as a continuous time stochastic lot-sizing problem. The proposed methodology employs, in large, Monte Carlo simulation which allows to consider various parameters of the system (e.g. failures) that cannot be deterministically defined. The numerical procedure has been validated using a set of randomly selected data. The integrated decision model can be easily generalized and applied in any manufacturing system. Implementation on a popular ERP system corroborates the work.

■ TC-26

Tuesday, 12:30-14:00 - F106

OR and Ethics and Societal Complexity I

Stream: OR and Ethics

Invited session

Chair: *Ulrike Reisach*

1 - Application of the oral health education program and its influence on the level of knowledge, oral hygiene and salivary pH of school children

Maria Elena Huauya Leuyacc

Introduction: Oral health is an indispensable component of general health because it contributes to the physical, psychological and social well-being of people. The populations with the highest burden of oral disease are related to living conditions, certain environmental and behavioral factors, health systems and the application of preventive programs in this area; being the school stage the most important for the implementation of healthy habits. Objective: To determine the influence of the application of the Oral Health Education Program on the level of knowledge, oral hygiene and salivary pH of school children. Material and methods: The research design was pre-experimental with previous and subsequent tests. The population consisted of a total of 250 boys and girls, enrolled in the sixth grade of primary education, and the sample of 100 children of both genders was obtained by the non-probabilistic sampling technique of intentional type; the data was processed with the IBM SPSS statistical software, and for the hypothesis testing the Student's T statistic was used for the related samples. Conclusions: The statistical results show, in general, that the application of the Oral Health Education Program significantly influences the level of knowledge, oral hygiene and salivary pH of the children under study, which is why it is recommended at school and also at pre-school level, thus generating a new culture in oral health.

2 - Multimethodology for improving the inclusion of students with SEN

Mischel Carmen N. Belderrain, Rafael Verão Françozo

Inclusion of students with Special Educational Needs (SEN) is an important educational policy in Brazil. The aim of this paper is to develop a multimethodology composed of Soft System Methodology (SSM) and Value Focused Thinking (VFT). VFT is used for selecting the transformations of SSM according to the values and objectives of stakeholders. Multi-methodology proved to be adequate for this problem, generating concrete actions leading to the assurance that students with SEN will face equivalent, proportionate conditions as any regular student regarding the attributes of equity, ethics, quality, entrepreneurship and innovation.

3 - Democratic or not? Democracy indices unveiled by OR

Cindy-Ricarda Roberts, Magdalena Wagner

The aim of the research is to discuss possible applications of operational research in political science with respect to democracy. Political science is a multidisciplinary field and comprises various aspects of other disciplines, such as: economics, law, sociology, geography, philosophy, and psychology. It seems fair to say that operational research is an interesting, yet not thoroughly investigated, solution to this discipline. This research offers a simple example of how to use and incorporate operational research into problem structuring within political science, namely by measuring quality of democracy. In the presented case study, OR methods (e.g. DEMATEL method, which is used for catching causal-effectual interdependencies between factors of a system) are examined and offered as a solution for assessing the state of democracy in the world. Democracy indices are based on various criteria and indicators of democracy such as (among others): rule of law, free and fair elections, human rights, or public sphere. The research presents an analysis of selected democracy indices, e.g. the Democracy Index, the Democracy Barometer, or the Freedom in the World. The conclusions drawn from this research illustrate how operational research could be incorporated into the field of political science in order to provide more transparent, reasonable, and efficient framework towards democracy indices.

4 - Real Time Delphi for understand the variability of decisions about violated children and teenager
Regiane Maximo Siqueira, Ailton Souza Aragão, Carlos Bana e Costa, Flávia Trevizan Fernandes, Hugo Henrique Santos

The professionals involved in analysis and decision to guarantee rights violated children and teenager have multiple backgrounds, from doctors, nurses, social workers, until judges and promoters. Such plurality may result inconsistencies as to the best deliberation for the protection of victims. A Real Time Delphi conducted in three rounds is proposed without depending on local legislation. The first round aims to understand how the variability of the decisions, is composed of open questions to each type of violence. According to each definition, the specialist has described: a case experienced; the referencing; the options for referencing; the factors that led to the referencing. We analyze typical situations without the expert being exposed in an embarrassing situation or refer to a past personal experience, minimizing biases and preserving ethical aspects. The expert can reply the questionnaire as many times as he/she can, see previous answers and edit his answer until the first round closed. At the end of the session, the experts complete a socio-demographic questionnaire with issue construct a profile. The two closed rounds aim to obtain consensus on the decisions presented in the first round. The cases and decisions are presented to the experts so that they agree or disagree, in the form of Likert scale, of decisions case described, recording their comments. The process has individual feedback for each panel member incorporated into the process.

■ TC-27

Tuesday, 12:30-14:00 - F107

Financial Mathematics and OR 2

Stream: Financial Mathematics and OR
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Yuriy Kaniovskyi*
Chair: *Li Zhongfei*

1 - Financing, investment, liquidation, and costly reversibility
Takashi Shibata, Michi Nishihara

We examine the interaction between financing and investment decisions under the condition that debt holders have the option of maximizing the debt-collection amount if a firm is liquidated during financial distress. We add to the literature by incorporating debt holders' optimization considerations related to the debt-collection amount. We show that if the debt-collection amount increases ex post when the firm is liquidated, the firm increases the amounts of debt issuance and investment quantity ex ante, delaying the corporate investment. This relationship is based on the fact that an increase in the debt-collection amount decreases the credit spread of debt holders. These results fit well with those of existing empirical studies.

2 - Reducing Estimation Risk Using Bayesian Approach: Application to Stress Testing Mortgage Loan Default
Zheqi Wang, Jonathan Crook, Galina Andreeva

We propose a new stress testing method to reduce estimation risk by using Bayesian approach. We model stress coming from both macroeconomic shocks and coefficient uncertainty. Based on the U.S. mortgage loan data, we model probability of default at account level using discrete time hazard analysis. We employ both frequentist and non-informative Bayesian methods in parameter estimation and default rate stress testing. The Bayesian method is employed in order to simulate the posterior distribution of the model parameters. The parameter posterior distribution obtained in the Bayesian approach is subsequently applied in stress testing to form the Bayesian simulated default rate (DR) distribution to reduce the estimation risk coming from using point estimates in stress testing. The Bayesian simulated DR distribution is compared with the frequentist simulated DR distribution which uses parameter mean estimates. We find that the simulated DR distribution obtained using the Bayesian approach with parameter posterior distribution has larger spread and variance than that using the frequentist approach with parameter mean estimates. Moreover, the 95% and 99% value at risk (VaR) of the estimated DR using the Bayesian approach is higher than the VaR of the same probability levels using the frequentist approach.

3 - Model identification and parameter estimation for huge latent distributions: macroeconomic scenarios and credit-rating migrations
Yuriy Kaniovskyi, Georg Pflug

If M non-default credit classes and S industries are considered, the number of parameters defining the distribution of credit-rating migrations grows exponentially in MS. They are estimated from historical migration counts. If M=7 and S=6, several trillion parameters have to be estimated from a hundred thousand of counts. The peculiarity of the problem is that the state space of the hidden distribution is huge, but its support is known to be relatively small. Using standard (non-convex) optimization techniques, an approximation to the support is identified and the solution is step-wise improved in a heuristic manner as a sequential or as a parallel algorithm. The approach is typical for a large class of problems, where a discrete hidden distribution governs the evolution of the observable data.

4 - Analysis of financial derivatives hedging bunker fuel price volatility in container shipping
Dongping Song, Tianyu Song

Bunker fuel consumption accounts for the majority of a ship's operating cost. The volatility of bunker fuel price has been a serious risk to shipping companies' cash flow. To mitigate the risk and reduce operational cost, it is common for ocean carriers to adopt financial derivatives, e.g. forward, option and their variants, to hedge the volatility of bunker fuel price. However, there is no research in the literature to analyze such financial derivatives in a systematic way. This study will address the following research questions: 1. Identify the common financial derivatives that have been used to hedge against bunker fuel risk; 2. Evaluate the effectiveness of the identified financial derivatives in a liner shipping service; 3. Compare the relative advantages of different financial derivatives and identify which financial derivative is preferable in which situation. The first research objective will be achieved by conducting a comprehensive literature review. To achieve the second and third objectives, a typical liner shipping service will be selected, and then simulation method will be used to model the dynamic operational system subject to uncertain bunker fuel price. Based on the Monte Carlo simulation, the effectiveness of these financial derivatives and their relative advantages will be obtained. The results will provide useful managerial insights to shipping companies to select appropriate financial derivatives to hedge against fuel price volatility.

■ TC-28

Tuesday, 12:30-14:00 - G102

Financial challenges in Cryptocurrencies

Stream: Blockchain and Cryptocurrencies: Economic and Financial Challenges
Invited session
Chair: *Gianna Figà-Talamanca*

1 - Cointegration analysis of cryptocurrencies
Marco Patacca, Sergio Focardi

Cryptocurrencies are going to become an important payment tool as well as an asset class for investment. There are several online exchanges for buying/selling cryptocurrencies and specialized online platforms for trading not only cryptocurrencies but also future and options. Furthermore, an increasing number of important online shops, such as Expedia and Overstock, accept payments in cryptocurrencies. In this paper, we propose a multivariate analysis of cryptocurrencies prices. First, we analyze if prices are stationary, integrated or explosive time series, and we conclude that we cannot reject the assumption that they are integrated series. We study cointegration between the major cryptocurrencies with various criteria and we find that prices admit one single integrated common factor. Applying the Stock-Watson procedure, we perform the PCA of prices to compute common trends and we analyze the forecastability of prices. Based on the results of these analyses, we propose long short strategies. To complete our study, we conduct also a multivariate analysis of the first differences of prices. Given the specific nature of cryptocurrencies, we first test for Markov switching behavior. We find that the major currencies admit 2 states and the permanence in each state are highly mutually correlated. We perform a MS-VAR analysis and we propose a theoretical framework to integrate the previous analysis in terms of cointegration with the latter in terms of MS-VAR.

2 - Are cryptocurrencies true money? An analysis based on the theory of money
Sergio Focardi, Marco Patacca

Are cryptocurrencies true money? In this paper we address this question from the point of view of the theory of money. We propose a conceptual framework based on four fundamental questions: 1) What is the nature of money? 2) How is new money created? 3) How is new money distributed? 4) How does money acquire and keep or change value? Today money takes two principal forms, banknotes and bank deposits. Banknotes are the most fundamental form of money but, in practice, their importance is marginal: the bulk of money is formed by bank deposits. Cryptocurrencies and bank deposits share the same nature of being numbers written in private computers. However, the rules that govern the creation and allocation of new bank deposits are critically different from the creation of cryptocurrencies. In fact, the amount of traditional currencies increases when someone takes out a debt or when the central bank purchases assets from non-banks while new cryptocurrencies are generated by the actions of miners who generate them for their own profit and then sell them to other individuals. The difference of the two rules in building confidence is paramount. The value of cryptocurrencies depends on supply and demand of the currencies, while the value of traditional currencies is determined by their purchasing power. Using the theory of money, we analyze the issues of large scale use of cryptocurrencies and we discuss if and how they could become the main currency.

3 - Bubble regime identification in an attention based model for BitCoin dynamics
Gianna Figà-Talamanca, Alessandra Cretarola

In this paper we generalize our previous contribution to account for regime switches in the correlation between BitCoin returns and a market attention factor. The model is then estimated on real data and a bubble regime is identified when the correlation relative to one state of the hidden Markov chain is above a fixed threshold. By applying the suggested method BitCoin is shown to be in a bubble during the years 2013-2014 and during the year 2017, consistently with other research papers.

■ TC-29

Tuesday, 12:30-14:00 - C118

Big Data III

Stream: Big Data in Complex Systems
Invited session
Chair: Yanou Ramon

1 - Influential Node Detection Based on Graph Neural Networks
Eunji Jo, Sang Yong Lee, Dohyun (Norman) Kim

Recently, a lot of attention has been paid to graphs in various areas of science and engineering including biochemistry, social science and bibliometrics. A graph is a data structure to consists of the objects (nodes) and their relationship (links). In graph analysis, detecting influential nodes is an essential task to identify nodes to maximize the diffusion of information in graphs. To detect influential nodes, many centralities have been proposed. However, existing centralities does not quantify the influence of nodes by simultaneously considering the graph structure and node attributes. Developed in this article is an influential node detection method considering the graph structure and node attributes based on graph neural networks (GNNs), which the deep learning-based methods extended to analyze graphs. GNNs generally can update the features of nodes by aggregating features of their neighborhood. Therefore, GNN can effectively identify influential nodes by simultaneously considering graph structure and node features. Experimental results show that GNN is a useful alternative when identifying influential nodes.

2 - A Study on the Prediction of Apartment Price Based on Artificial Intelligence
Sungho Park, Kangbae Lee, Doo-hwan Kim, Sangha Sung, Jihwan Baek

Real estate assets account for the largest portion of domestic household assets, and apartments account for the largest portion of real estate assets. In Korea, apartments are recognized not only as housing but also as assets. A study on various methods for the economic evaluation of apartments was carried out while the apartments were recognized as assets. Although many previous studies have applied various regression models, there is a problem in that the prediction accuracy of the prediction model is lowered due to under-fit, multi collinearity, over-fit, and under-fit that occur in the regression model. Therefore, in this study, we proposed various artificial intelligence methods to overcome limitations of existing regression models and to predict apartment prices. The analysis of this study is the apartments traded in the Busan area for five years from 2012 to 2016. The distance between apartments and apartment properties is calculated not by simple straight distance but by actual road distance reflecting the state of the road network in the city. By analyzing the relation between apartment and apartment properties, it is analyzed as macroeconomic variable and hedonic variable. A variety of public databases were used for data collection, and the collected data were researched using the statistical methods of regression analysis and machine learning methods such as Random Forest, SVM, and DNN.

3 - Comparative study of instance-level explanations for big, sparse data
Yanou Ramon, David Martens

Predictive modeling applications using high-dimensional, sparse data are ample, and range from document classification to mining behavioral data. Examples include predicting product interest based on online browsing data or Facebook likes, predicting spam emails, and detecting objectionable web content.

The high-dimensional and sparse nature of the data brings serious transparency issues for predictive models that are built on such data: even linear models require investigating thousands of coefficients, while non-linear models amplify the problem even further. However, explainability of the predictions made is crucial for trust, to accept predicted outcomes and to gain relevant insights.

In this paper, we provide an overview of existing explanation methods, with a focus on instance-based explanations, that are particularly suitable for this data type. We compare three techniques (EDC, SHAP, LIME) using both quantitative and qualitative experiments. The evaluation criteria that are considered follow a framework that takes into account who the explanations are for (eg, manager, customer or data science team), and include algorithmic efficiency, explanation effectiveness and subjective preference.

■ TC-30

Tuesday, 12:30-14:00 - C007

The Role of Mathematical Optimization in Data Science II

Stream: Data Science Meets Optimization
Invited session
Chair: Vanesa Guerrero

1 - Tree-Structured Data Clustering with Graph Edit Distance

Derya Dinler, Mustafa Kemal Tural, Nur Evin Özdemirel

Clustering aims to partition the given data objects into groups in such a way that objects in the same cluster are similar while they are different than the objects in other clusters. Traditional clustering problems deal with data objects represented as points. However, in recent years, improving measurement capabilities and the need for deeper analyses result in more complex data objects such as regions or graphs. In this study, we consider a clustering problem in which the data objects are m-ary trees with unweighted nodes, and unweighted or weighted edges. We assume that the node correspondence between trees is known. For the solution of the problem, we propose k-means based algorithms which start with initial centroid trees and repeat assignment and update steps until convergence. In the assignment step, each data object is assigned to the most similar centroid determined by the Graph Edit Distance (GED). In the update step, each centroid is updated by considering the data objects assigned to it. We propose an Integer Linear Programming formulation and a Mixed Integer Nonlinear Programming formulation to find the centroid of a given cluster, which is the tree minimizing the sum of GEDs, for unweighted and weighted edges cases, respectively. We solve these formulations to optimality. We experiment with randomly generated and real life datasets, and compare the results with those of the traditional k-modes and k-means algorithms.

2 - Preferences Estimation Under Bounded Rationality: Identification of Attribute non-attendance using SVM

Veronica Diaz, Ricardo Montoya, Sebastian Maldonado

There is growing interest in Economics regarding the problem of estimating consumers' preferences when they partially ignore the information provided in choice experiments, a problem introduced in this field as attribute non-attendance (Hensher et al. 2010, Scarpa et al. 2009). This line of research explores the consequences of assuming that consumers use all available attributes to evaluate the alternatives when in fact they ignore some attributes. Diverse choice models have been developed to identify non-attendance from choice data. For instance, in latent class models each segment corresponds to a particular combination of relevant and irrelevant attributes. Due to the combinatorial nature of such an approach, researchers typically explore a limited number of specifications.

In this work, we propose the use of a machine learning approach based on Support Vector Machines to identify the non-attendance of attributes at individual level and to predict the consumer choices in a conjoint experiment. We conduct an extensive simulation study to investigate the performance of the proposed approach. We compare the performance of our proposed approach to different benchmarks from the literature. Our results with simulated data show a higher performance in terms of the identification of the non-attended attributes that improves the predictive ability of consumers' choices.

3 - On the construction of Optimal Randomized Regression Trees

Cristina Molero-Río, Rafael Blanquero, Emilio Carrizosa, Dolores Romero Morales

Classic regression trees are defined by a set of orthogonal cuts, i.e., the branching rules are of the form variable X not lower than threshold c. Oblique cuts, with at least two variables, have also been proposed, leading to generally more accurate and smaller-sized trees. The variables and thresholds are obtained by a greedy procedure. The use of a greedy strategy yields low computational cost, but may lead to myopic decisions. The latest advances in Optimization techniques have motivated further research on procedures to build optimal regression trees, with either orthogonal or oblique cuts. Mixed-Integer Optimization models have been recently proposed to tackle this problem. Instead, we propose to build optimal regression trees by solving nonlinear continuous optimization problems. This is achieved by including a cumulative density function that will indicate the path to be followed inside the tree. In contrast to classic regression trees, our formulation is flexible enough since sparsity or preference of performance in a subsample could be easily included.

4 - Gaining Insight into Data Through Mixed Integer Nonlinear Programming

Vanesa Guerrero, Emilio Carrizosa, Dolores Romero Morales

Extracting knowledge from data, such as dependencies, global underlying patterns or unusual behaviors, has become a crucial task for analysts to improve decision making. Nevertheless, the increase in data complexity has made, in some cases, the classic statistical models obsolete, and more sophisticated frameworks are thus needed. In this context, Mathematical Optimization plays an important role, both developing new models and algorithmic approaches as well as creating new frameworks, which gain insight into specific datasets' features and cope with nowadays requirements. In this talk, we discuss how mixed integer nonlinear programming helps to draw conclusions about statistical dependencies between categorical variables along with its power to the enhancement of interpretability in latent variable models.

■ TC-31

Tuesday, 12:30-14:00 - G108

Operating Room planning and scheduling

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Roberto Aringhieri
Chair: Julian Schiele

1 - A model for continual surgery allocation

Troels Martin Range, Dawid Kozlowski, Niels Christian Petersen

Elective patients are referred to surgery on a continual basis. In real-world settings the patients are often booked by a manual planner selecting a suitable surgery slot for each patient in a first-come-first-served manner. This approach may lead to inefficient utilization of resources. Furthermore, if resources are scarce then it may not be possible to offer patients surgery within a given deadline.

In this presentation we discuss recurrent use of a model based on column generation to allocate patients to surgeries. Patient arrivals follow a stochastic arrival process for each patient category. Making decisions only on currently known patients will limit the possibilities for patients arriving in the future. This problem is the focus of the presentation.

The model distinguishes itself from other models for surgery allocation by having a look-ahead mechanism where non-arrived patients are allocated to tentative surgery slots such that an expected target service level is achieved to the highest possible degree. This allows us to distinguish between patient categories having different deadlines. Furthermore, the model allows for potential overtime of the resources as well as closing resources.

We test four scheduling policies with different levels of optimization using a simple discrete event simulation approach in which the model is embedded. The tests show that applying the look-ahead mechanism will increase the service level for the patients.

2 - Scheduling Surgical Operations and the Post-Anesthesia Care Unit Using Work Tours and Binary Programming

Barry King

When surgical patients leave an operating room, they go to the post-anesthesia care unit (PACU) to recover. The PACU is shared by multiple operating rooms (OR) and receives patients with varying levels of acuity from multiple specialties. The volume of patients coming from the OR to the PACU can vary greatly depending upon the complexity and duration of the surgical procedures. In addition, the amount of time required in the PACU can also vary greatly depending upon the level of sedation and response of the individual patients. A problem for the operating room scheduler is to schedule operations such that the PACU is not requested to take more patients than it can handle while accommodating requests from the surgeons and the patients. Each hospital is different and there is no generic scheduling system to assist the scheduler. A common approach to OR scheduling is to maximize the utilization of both the operating rooms and the surgeons without regard to the effect that this maximization might have on the downstream PACU or the patients being admitted to an inpatient unit in the hospital. A regular request from surgeons is to schedule their complex cases early in the morning and the less complex (shorter) cases later in the day. The solution is to develop work tours for operating time/PACU time pairs spread throughout the day and employ a binary integer programming formulation that not only obeys the PACU capacity constraint but also handles other scheduling constraints.

3 - Predicting surgery durations to optimize the operating room efficiency

Julian Schiele, Thomas Koperna, Jens Brunner

The operating room is the most critical resource and a major cost driver of a hospital. In times of increased economic pressure, it is of utmost importance to ensure an efficient utilization of the operating room environment. On the operational level, hospital practitioners are asked to schedule elective surgeries for individual patients. Usually, they have several objectives in mind, such as completion of all surgeries, impact on downstream units, and over- and undertime of staff. Accurate predictions of surgery durations are essential to ensure efficient surgery scheduling. However, in most hospitals, those predictions are either based on historical average values or expert estimates. Both approaches exhibit significant shortcomings making them prone to inaccuracy, i.e., negligence of patient specific information, lack of quantitative models, and financial bias. We present a generalizable machine learning approach to predict surgery durations for individual patients. Our model is based on a variety of clinical and non-clinical features. We provide an empirical evaluation of our method with 7 years of surgery data from Universitätsklinikum Augsburg, a German tertiary care hospital having 1,700 beds and serving all surgical specialties. Our research has been conducted in close collaboration with the hospital management and will serve as foundation for a new operating room management system ensuring lasting impact on operational efficiency and improved quality of care.

4 - The re-planning and scheduling of surgical cases in the operating room department after release time with resource rescheduling

Babak Akbarzadeh, Broos Maenhout

The decisions in the operating room scheduling process related to the case mix planning and the master surgery schedule are based on the expected surgical demand, predicted by historical data. However, in operational level, the actual surgical demand may differ from the expected demand. In this paper, we study the surgical case planning and scheduling problem with resource re-scheduling that arises at cut-off time where the surgical demand become more accurate. To match supply and demand, changes with respect to the master surgery schedule, the physician schedule and the nurse roster are considered to adequately plan and schedule surgical cases. The problem under study minimizes the cancellation and waiting time of surgical cases and the resource re-scheduling cost. We propose a three-phase heuristic that uses column generation to construct a high-quality feasible solution, which is further improved via local branching. Computational experiments have been conducted on an artificial dataset generated based on a real-life problem environment in a controlled and structured manner. Results that our approach is able to produce (near-)optimal solutions and show the contribution of the different algorithmic building blocks. Keywords: OR in health services; Operating room department, Cut-off time, Resource re-scheduling, Surgical case planning and scheduling

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■ TC-32

Tuesday, 12:30-14:00 - G109

Sports timetabling: applications

Stream: OR in Sports
Invited session
Chair: Dries Goossens

1 - On the flexibility of Home-Away pattern sets

Frits Spieksma, Roel Lambers, Dries Goossens

We consider the scheduling of a sports league in a round robin, compact format. We assume, as in practice, that in such a compact schedule, from the viewpoint of a team, each match is played either at home, or away. This gives rise to a Home-Away pattern (HAP) for each team. Deciding upon which matches are played in which round is of great practical importance, and a popular way to do so is a first-break-than-schedule approach. In such an approach, first a HAP is chosen for each team, resulting in a set of patterns denoted by the pattern-set H. Next, the individual matches are assigned to rounds in a way that is compatible with this pattern-set. The goal of this contribution is to investigate to what extent the choice of the pattern-set leaves room for the assignment of individual matches to rounds. Indeed, we will show that not all pattern-sets H are created equal, and that some pattern-sets allow more flexibility than others. We introduce measures that indicate the flexibility of a HAP-set, and, for particular pattern-sets known as the Canonical Pattern Set, we compute their values.

2 - Scheduling the 2019 Cricket World Cup

Mike Wright

The men's Cricket World Cup is taking place in England and Wales between May and July 2019. This is a major tournament of interest worldwide and is expected to attract television audiences of up to a billion, possibly even more. Of course, this tournament needed to be scheduled, and it was very important to all competing teams, the game's administrators, televisers and sponsors that this was done as well as possible, so as to optimise a number of sporting and financial considerations.

The problem involved scheduling matches not only to dates but also to venues. There were different considerations and restrictions for different teams and venues; moreover, not just dates but times of day were important, and not just venues but their regions were important when evaluating the quality of any proposed schedule. Thus this was a highly non-standard problem which required a bespoke solution approach.

A simulated annealing method was used for which constraints, costs and neighbourhood moves concerned not just dates and venues separately but also their combination. Although political considerations took precedence at the last minute, and the schedules produced by the system were not eventually used, the scheduling system proved very successful in producing schedules of very high quality, demonstrating that a metaheuristics approach can work well for very complex sports scheduling problems for very demanding stakeholders.

3 - Scheduling the Argentina's Football Superliga
Guillermo Durán, Mario Guajardo, Gonzalo Zamorano

The main professional football league of Argentina has currently 26 teams. The 2018-19 season consists of a single round robin tournament, that is, every team plays against each other one match at the home venue of one of them. This can create potentially large differences in the distances travelled by the teams over the course of the tournament, an important aspect in a league where a round trip to play an away match can involve more than 3,300 kilometres. In addition, as previous tournaments were scheduled manually, little care was taken about alternating the venue in which a same pair of teams would play. This implied that many matches took place at the same venue consecutively in several tournaments. In the most extreme case, a pair of teams played at the same venue for up to six consecutive tournaments. In what for this league was a breakthrough change, the 2018-19 season has been scheduled using an integer programming model. Among several other aspects, the model aims at providing a relatively even schedule of travels for neighbour teams and at changing the home venues of the matches that had been played at the same venue two or more consecutive times in the six previous tournaments. This talk will focus on the design, computational features, and the implementation in practice of this schedule.

■ TC-33

Tuesday, 12:30-14:00 - Q005

Modelling and Optimisation in Industrial Organisation III

Stream: Mathematical Modelling
Invited session
Chair: Celina P. Leão

1 - A Genetic Algorithm for Discovering Regular Plans for Mobile Clients
Ioannis Tsiligkaridis

The broadcast problem including the plan design is considered. Data are inserted and numbered at a predefined order into customized size relations. The server fetches the requests and broadcasts the data to the air. To address the problem, focus is given on the computation of the size of data of different services so that a Regular Broadcast Plan (RBP) or RBPs are feasible. For the server, a set of algorithms can guarantee the creation of a full RBP with equal spacing repeated items using single or multiple channels. The Basic Regular Algorithm (BRA) and the Partition Value Algorithm (PVA) can provide a static and dynamic RBP construction with multiple constraints solutions respectively. A set of theorems, that are fundamental for both the creation of an RBP and the ability to provide a new criterion for the non equal subrelations, are presented. A Genetic Algorithm (GA) is selected for optimization. A GARP algorithm is developed and it can find solutions for servers with diversity of services and big size messages. Solutions with equal and different subrelations are provided. GARP discovers the RBPs using genetic operators. Criteria for the discovery of RBPs are used to prepare the conditions for the development of GARP. Fitness is based on a combination of criteria. GARP can also be applied for the discovery of RBP with a minimum number of channels. Modern servers can enhance their self-sufficiency, self-monitoring, and quality of service with minimal human intervention.

2 - Multi-Objective Decision Support for Projects with Stochastic Time-cost Trade-offs
Lucas Merschbächer, Alexander Baumeister

Project optimization oftentimes requires stochastic, multi-criteria models focusing on cost, time and quality. Especially time-cost trade-offs, e. g. accelerating activities by additional team members, come along with project flexibility and can be used as a means of project risk management. While stochastic scheduling of projects is well researched in general under the assumption of stochastic independency, time-cost-quality trade-offs in projects require the modeling of dependence structures. However, closed analytic solutions then are hard to obtain. Therefore, we use a simulation approach based on copulas for handling project dependencies. It supports decisions of project risk management by an ongoing evaluation of possible adjustments of the project's structure or activities. For illustration, we first present a simplified model of stochastic project optimization focusing on time-cost trade-offs and then expand it by introducing copulas.

3 - Performance Indicators Definition Through Data Analysis And Interpretation - A Case Study
Celina P. Leão, Inês G. Barros, António Amaral

The complexity of management systems has created the need for simpler and easier-to-understand information systems tools to improve business performance. Whilst, knowing that when we measure we become more conscious and aware of what is happening in the organization, decision-making turns out to be an easier management procedure with higher chances of being accurate. It is at this point that the Key Process Indicators (KPI) for logistics emerge. These KPIs allow us to measure company performance by enabling us to plan across all hierarchical levels, as well as to follow the objectives of the predefined strategies. Our main goal is to study the logistic activities and its level of effectiveness, towards defining and analysing performance indicators, focusing exclusively on transportation. Firstly, assessing the existent performance indicators available in the Logistics Department of a specialized company in design, production and assembly of medium and large size metallic structures. Then, and due to the need to improve company's performance and efficiency, new indicators (KPIs) were developed and monitor. The implementation of a dashboard with important organizational' information was also suggested. Three out of eight proposed KPIs were classified and implemented. As a contribution, we highlight the integration of three perspectives outlined in the Balanced Scorecard (Financial, Customer, Internal Processes) into the KPIs.

■ TC-34

Tuesday, 12:30-14:00 - Q006

Multiobjective Optimization and Real World Applications II

Stream: Multiple Criteria Decision Making and Optimization (contributed)
Contributed session
Chair: Matthias Ehrgott

1 - Multi-Objective Route Planning of a Fleet of Unmanned Aerial Vehicles
Büşra Bişkin, Diclehan Tezcaner Öztürk, Ceren Tuncer Sakar

Unmanned Aerial Vehicles (UAVs) are widely used for several missions with different purposes. In this study, we aim to route a UAV fleet that consists of homogenous UAVs considering multiple objectives. The fleet takes off from a base point and visits a number of targets in a two-dimensional terrain. The routes are determined considering flight distance capacities of UAVs and different priorities of targets. We find efficient routes for each UAV in the fleet and the trajectory between each target in every route by minimizing the total distance traveled by the fleet and the total radar threat, and maximizing the total reward collected from the targets. We model our problem with a Mixed Integer Linear Programming formulation and find exact solutions for small-sized problems. In order to handle three objectives in bigger-sized routing problems, we utilize an adjusted NSGA-II algorithm taking preferences of the decision maker into consideration.

2 - A Bayesian production, maintenance and quality model for processes in big data environments

Konstantinos Tasias, George Nenes, Sofia Panagiotidou

In contemporary manufacturing processes a huge volume of data may be easily provided through multiple sensing devices. The challenge is to develop appropriate models which will manage to exploit efficiently the sensing data by transforming it into optimal decisions that add real value to the monitored process. To this effect, we present a Bayesian model that optimizes jointly production quantity, maintenance policy and quality control in a big data framework. The proposed control scheme dictates optimal decisions for the three aforementioned interrelated process aspects through on-line monitoring techniques. The quality of the process output is fully characterized by multiple correlated quality characteristics and the process is subject to multiple quality shifts and failures. Moreover, the joint determination of production, maintenance and quality policy is defined through both economic and statistical criteria. These realistic assumptions lead to the development of a general, advanced, big data-driven and widely applicable tool in the field of modern operational research.

3 - Multicriteria approach to define Social Justice Indicators within the Responsible Research and Innovation framework

Cristobal Miralles, Irene Monsonís-Payá, Monica Garcia-Melon

During the last decade, the Responsible Research and Innovation (RRI) concept is being promoted as an open dialogue for promoting the participation of civil society in the field of research and innovation, which is especially important in the actual disruptive scenario that new technologies are fostering. The RRI framework has been articulated by the European Commission around six areas: governance, public engagement, gender equality, science education, open access&science, and ethics; but still needs reflection and a broader debate regarding a key transversal topic: Social Justice.

This exploratory research starts with the discussion of certain basic hypothesis and a critical&extensive review of the potential indicators initially useful to monitor this dimension in the Spanish context. Then, the multicriteria analysis technique Analytical Hierarchical Process (AHP) is used to prioritize indicators, weighting and selecting them according to the opinions of experts in different areas. Finally, some discussions arise on the strengths and challenges of this bottom-up approach, as normative proposals are necessary to apply these indicators within the decision making process both to assess and orientate public scientific policies.

This research was funded by the Spanish Ministry of Economy, Industry and Competitiveness project INPERRI (CSO2016-76828-R), and by Generalitat Valenciana competitive project AICO/2018/270.

4 - Evaluating the Quality of Radiotherapy Treatment Plans for Prostate Cancer

Matthias Ehrgott, Emma Stubington, Glyn Shentall, Omid Nohadani

External beam radiation therapy is a common treatment method for cancer. Radiotherapy is planned with the aim to achieve conflicting goals: while a sufficiently high dose of radiation is necessary for tumour control, a low dose of radiation is desirable to avoid complications in normal, healthy, tissue. These goals are encoded in clinical protocols and a plan that does not meet the criteria set out in the protocol may have to be re-optimised using a trial and error process. To support the planning process, it is therefore important to evaluate the quality of treatmentplans in order to recognise plans that will benefit from such re-optimisation and distinguish them from those for which this is unlikely to be the case. In this talk we present a case study of evaluating the quality of prostate cancer treatment plans based on data collected from Rosemere Cancer Centre at the Royal Preston Hospital in the UK. We use Principal Component Analysis to select the most relevant data. We then apply Data Envelopment Analysis to assess the quality of individual plans. Each plan is compared against the entire set of plans to identify those that could realistically be improved. We further enhance this procedure with simulation techniques to account for uncertainties in the data for treatment plans. The proposed approach to plan evaluation provides a tool to support radiotherapy treatment planners in their task to detto determine the best possible radiotherapy treatment for cancer patients.

■ TC-35

Tuesday, 12:30-14:00 - Q009

Game Theoretical Models and Applications IV

Stream: Game Theory, Solutions and Structures
Invited session
Chair: Marco Slikker

1 - Some remarks on assortative multisided assignment games

Javier Martinez-de-Albeniz, Carles Rafels, Neus Ybern

We analyze assortative multisided assignment games, following Sherstyuk(1999) and Martínez-de-Albéniz et al. (2019). In them players' abilities are complementary across types (i.e. supermodular or inverse Monge) and also agents are ordered by some trait, and each trait has a monotone effect on the output, higher values have a larger effect. Multisided assignment games are the natural extension of the bilateral assignment model, and were introduced by Quint (1991). We study the core of the related game which is always non-empty and show which are the extreme core points. We give an easy way to compute them, and some properties. We give a formula to compute the best core allocation for each type, sectors-optimal core allocation. Then we find a natural solution for these games. It coincides with several well-known point solutions.

2 - A stochastic approach to some values in cooperative games

Stefano Benati, Fernando Lopez-Blazquez, Justo Puerto

We consider the problem of calculating values of a cooperative games (N,v). Many values, such as Shapley, semi-values, Least Square Values, have additive forms, but summations range on an exponential number of terms, making exact value computation unpractical even for moderate size games. We suggest calculating an approximation of values, selecting only few summation addends through peculiar sampling schemes. Our approach is based on re-phrasing the original deterministic game as a stochastic one, in which values are calculated as Expectations, and on which other distribution moments, as Variances, can be assessed. As a result, we can established an estimation theory on values of cooperative games. We applied our approach to some benchmark games, using different value concepts and different sampling strategies. First, as applied to the mean value of a game and to games with known closed formulas values, e.g., the airport and the gloves game, we show that we calculate estimates that, as measured by standard errors, are pretty close to the true ones. Next, as applied to voting, production and assignment games, and using stratified sampling, we show that our method outperform previous estimation methods to a large extent.

3 - Stratified pooling versus full pooling: (non-)emptiness of the core

Marco Slikker, Loe Schlicher, Willem van Jaarsveld, Geert-Jan van Houtum

In this paper we study several service providers that keep spare parts in stock to protect for downtime of their high-tech machines and that face different downtime costs per stock-out. Service providers can cooperate by forming a joint spare parts pool, and we study the allocation of the joint costs to the individual service providers by studying an associated cooperative game. In extant literature, the joint spare parts pool is typically controlled by a suboptimal full-pooling policy. A full-pooling policy may lead to an empty core of the associated cooperative game, and we show this result in our setting as well. We then focus on situations where service providers apply an optimal policy: a stratification that determines, depending on the real-time on-hand inventory, which service providers may take parts from the pool. We formulate the associated stratified pooling game by defining each coalitional value in terms of the minimal long-run average costs of a Markov decision process. We present a proof demonstrating that stratified pooling games always have a non-empty core. This five-step proof is of interest in itself because it may be more generally applicable for other cooperative games where coalitional values can be defined in terms of Markov decision processes.

■ TC-36

Tuesday, 12:30-14:00 - Q010

Exact Methods for Vehicle Routing Problems I

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Albert Schrotenboer*

1 - A branch-cut-and-price algorithm for the generalized vehicle routing problem

Mohammad Reihaneh, Ahmed Ghoniem

We develop a branch-cut-and-price algorithm for the generalized vehicle routing problem (GVRP)_ a variant of the vehicle routing problem where customers are partitioned into mutually exclusive clusters. The decision maker seeks to determine minimum cost routes using a limited number of vehicles such that every cluster is visited by exactly one route, and within any cluster a single customer is visited, subject to vehicle capacity constraints. The pricing subproblem is solved using a specialized dynamic programming algorithm. Computational results show that the proposed algorithm compares favorably against a state-of-the- art branch-and-cut algorithm and solves to optimality eight previously open GVRP instances in the literature.

2 - ng-Memory Based Capacity Cuts

Ymro Hoogendoorn, Kevin Dalmeijer

We present new valid inequalities for the capacitated vehicle routing problem (CVRP), called the ng-capacity cuts (ng-CCs). These valid inequalities are stronger than the rounded capacity cuts, but still have the attractive property that they are robust when the ng-route relaxation is used in a branch-price-andcut (BPC) algorithm. That is, including the duals of the ng-CCs in the pricing problem, a shortest path problem with resource constraints, does not require extra resources. In this paper, we formalize the concept of ng-robustness and we present the first ng-robust valid inequalities, the ng-CCs. This framework can facilitate the search for new ng-robust counterparts of known valid inequalities. Furthermore, we introduce different separation techniques for separating the ng-CCs and compare these numerically. We show that the separation of these cuts is equivalent to separating rounded capacity cuts on a modified graph. We present results on including the robust ng-CCs in a BPC-framework for solving CVRP benchmark instances, compared to using rounded capacity cuts. We also investigate for which types of problems these new valid inequalities outperform the rounded capacity cuts.

3 - Valid inequalities and a branch-and-cut algorithm for asymmetric multi-depot routing problems

Albert Schrotenboer, Michiel uit het Broek, Bolor Jargalsaikhan, Kees Jan Roodbergen, Leandro Coelho

We present a generic branch-and-cut framework for solving routing problems with multiple depots and asymmetric cost-structures, which consist in finding a set of cost minimizing (capacitated) vehicle tours in order to fulfill a set of customer demands. The backbone of the branch-and-cut framework is a series of valid inequalities, and accompanying separation algorithms, exploiting the asymmetric cost-structure in directed graphs. We derive three new classes of so-called DK inequalities that can eliminate subtours, enforce tours to be linked to a single depot, and impose bounds on the number of allowed customers in a tour. In addition, other well-known valid inequalities for solving vehicle routing problems are generalized and adapted to be valid for routing problems with multiple depots and asymmetric cost-structures. The resulting branch-and-cut framework is tested on four specific problem variants, for which we develop a new set of large-scale benchmark instances. The new DK inequalities are able to reduce root node optimality gaps by up to 67.2% compared to existing approaches in the literature. The overall branch-and-cut framework is effective as, e.g., Asymmetric Multi-Depot Traveling Salesman Problem instances containing up to 400 customers and 50 depots can be solved to optimality, for which only solutions of instances up to 300 customer nodes and 60 depots were reported in the literature before.

4 - The electric arc routing problem

Markus Leitner, Elena Fernandez, Ivana Ljubic, Mario Ruthmair

In company fleets (battery) electric vehicles (EVs) impose additional challenges due to their limited range enforcing time-demanding charging breaks during service in case of long trips and since their energy consumption heavily depends on the driving speed (among other factors). We study the use of EVs in the context of arc routing. Given a street network including a set of required arcs, the electric arc routing problem proposed in this work asks for a set of energy-feasible routes that visit all required arcs with minimal total travel time. While the use of EVs in arc routing has not been studied before, related works in node routing with EVs typically use several simplifying assumptions with respect to the energy consumption and / or charging functions. We address several of these shortcomings by considering speed dependent energy consumption values and nonlinear charging functions that depend on the battery state and the charging time. Additionally, we study the possibility of inductive (wireless) charging along roads while driving. We introduce the new problem and describe an integer linear programming formulation with an exponential number of constraints solved by a branch-and-cut algorithm. Furthermore, several heuristics based on a labeling algorithm are presented. In a computational study we analyze the performance of the algorithms and compare the solutions for different battery sizes, speed and charging options.

■ TC-37

Tuesday, 12:30-14:00 - Q011

Scheduling with Resource Constraints: Applications

Stream: Scheduling with Resource Constraints
Invited session
Chair: *Mariana Cunha*
Chair: *Anna Jellen*

1 - Ant Colony Optimization for the Film Production Scheduling Problem

Ching-Jung Ting, Kuan-Wei Chen

In film production, the cost of actors is one of the most important budgeting issues. In this study, we determine the sequence of the scenes of shooting days so that the total holding cost of actors' and the total operating cost of the shooting days can be minimized. We also consider the maximum daily working hours as the decision variable, which is defined as the total duration of scenes distributed in a single day. We first develop a mixed integer programming model. Since the problem is NP-hard, we propose an Ant Colony Optimization (ACO) algorithm to solve the film production scheduling problem. To access the effectiveness of the proposed ACO algorithm, we test three sets of benchmark instances from the literature. The first set includes 8 small sized instances. Our ACO can obtain all the optimal solutions. The second set has 240 instances. We can improve the best found solutions by up to 4.93%. The third set includes 1000 instances. We can found all best known soltuions. The computational results indicate that of our ACO algorithm are able to provide good solutions within short computational times.

2 - A flexible heuristic for the dual-resource constrained scheduling problem in quality control laboratories
Joaquim Viegas, Mariana Cunha, Miguel Martins, Tiago Coito, João Figueiredo, Joao Miguel da Costa Sousa, Susana Vieira

This work presents a novel heuristic for the dual resource constrained flexible job shop problem, considering both workers and machines. The problem is modelled considering workers are required multiple times to perform tasks while jobs are being processed by machines. Workers may be allocated to multiple ongoing jobs as long as tasks do not overlap. Furthermore, workers and machine eligibility constraints are considered, as well as precedence constraints between operations. A constructive heuristic based on the characteristics of each operation is developed and compared with a mixed integer linear programming model. Both solution methods use as objective minimizing makespan. The solution approaches were evaluated using generated instances based on real industry quality control laboratories. On small instances, results evidence the good solution quality of mixed integer linear programming and, on real size instances, the suitability of the heuristic approach is evidenced by the ability to reach good solutions in a reasonable amount of time, which is an important feature for operational applications.

3 - Optimization in dubbing scheduling problems
Silvia Lorenzo-Freire, Javier Piedracoba Castro, Roberto Asín, Maria Luisa Carpente, Antonio Fariña

One of the main tasks in dubbing studios is to design good schedules to assign actors to dubbing sessions. Brisaboa et al. (TOP, 2015) studied the problem of scheduling the work sessions in a dubbing studio for the actors included in the cast list of a film. The objective of the problem was to minimize the number of work sessions attended by the actors, trying not to exceed a given number of takes per session and assuming that each take must be dubbed, at most, in a limited number of work sessions. As a result, the scheduling problem should obtain the optimal assignment of takes and actors to available work sessions, thus determining which takes should be divided to guarantee the minimum actors cost. To solve this particular problem, they designed a heuristic algorithm that gets high quality solutions (an even the optimal) in just few seconds for real instances gathered from several dubbed films. In this paper, the availability of the actors at each period of the work sessions is taken into account. Moreover, we are not only interested in reducing the number of work sessions to be paid, but also in maximizing the free time at the end of the sessions. To solve the problem, we considered an integer programming model and designed a heuristic algorithm that achieves good solutions in reasonable computational times. Real instances from several dubbed films have been used.

4 - Solving a Real World Locomotive Scheduling Problem Considering Maintenance Constraints for the Rail Cargo Austria
Sarah Frisch, Philipp Hungerländer, Anna Jellen, Dominic Manuel Weinberger

This work discusses a variant of the Locomotive Scheduling Problem (LSP), where the aim is to assign a fleet of locomotives to a set of scheduled trains that must be performed, such that the overall costs are minimized. The rolling stock represents one of the main costs of a rail company, they are composed of the one-time investment for the acquisition and running costs for fuel and maintenances. Our aim is to reduce these costs by minimizing the number of locomotives used and the number of deadhead kilometers, which are kilometers driven by a locomotive without pulling a train. Compared to existing approaches for solving (variants of) the LSP we model this optimization problem on a sparse weighted directed multigraph considering maintenances of the locomotives. Based on this graph we propose a Mixed-Integer Linear Program (MILP) with three different objective functions. Due to the special structure of our graph we do not need to introduce variables for explicitly modeling the time component of the trains. This allows us to solve the MILP without applying heuristics, i.e., solve it exactly. We show that our MILP delivers high-quality solutions for the LSP in freight transportation and that it is applicable by the Rail Cargo Austria, on variable calendar dates and within a rolling horizon approach.

■ TC-38

Tuesday, 12:30-14:00 - Q012

Decision Aiding Methods 1

Stream: Multiple Criteria Decision Aid
Invited session
Chair: Theodor Stewart

1 - Aggregating opinions expressed in different qualitative scales
Raquel González del Pozo, Luis C. Dias, José Luis García-Lapresta

Some MCDM procedures are used to rank alternatives which are assessed by a group of agents using a specific ordered qualitative scale in each criterion. Generally, human beings prefer qualitative scales formed by linguistic terms rather than numbers due to the vagueness and imprecision of their judgments. When agents assess alternatives, sometimes it could happen that they can perceive different proximities between terms of scales, that is, agents can consider implicitly that some ordered qualitative scales are not uniform.

In the context of non-uniform qualitative scales, the typical numerical codifications that assign numbers to linguistic terms of qualitative scales are not appropriate, since they do not represent faithfully how agents perceive the proximities between linguistic terms.

In this contribution, we propose a MCDM procedure for ranking alternatives assessed by agents by means of a specific qualitative scale for each criterion. The proposed procedure is based on the concept of ordinal proximity measure [1]. Ordinal proximity measures deal with non-uniform qualitative scales in a purely ordinal way, avoiding numerical codifications to linguistic terms of scales. The proposed procedure is illustrated with a case study.

[1] García-Lapresta, José Luis and Pérez-Román, David (2015). "Ordinal proximity measures in the context of unbalanced qualitative scales and some applications to consensus and clustering". Applied Soft Computing, 35: 864-872.

2 - A referential framework for systematization and applicability assessment of weight specification methods in multi-criteria decision-making
Andrej Bregar

Specification of criteria importance weights is one of key steps in the process of multi-criteria decision-making. The aim of the presented research is to provide a thorough survey of classic and state-of-the-art approaches to weight specification, and systematize them into a referential model. The defined model classifies methods into three groups corresponding to direct weight derivation, indirect weight derivation and readjustment of existing weights. These groups are further structured into ordinal and ratio based approaches, utility and bargaining related approaches, fuzzy averaging operators, dominance and optimality methods, regression techniques, structural modelling and interactive procedures. By utilizing a common evaluation framework, the characteristics of key types of weight specification methods are determined. The framework allows decision-makers to assess the suitability of different methods for various problem settings and to select the most appropriate ones for application. Criteria of the proposed framework include the complexity and credibility of analysis, problem abstraction, format of judgements and methodology type. Several use cases are described in the context of preference elicitation and aggregation. The efficiency of indirect weight derivation techniques is empirically studied with regard to the regression on correlations between preferential parameters and referential sets of alternatives. Regression results are evaluated with a simulation model.

3 - Morphological Analysis supported Multiple Criteria Decision Analysis

Tobias Fasth, Cecilia Oksanen, Niclas Petersson

The problem definition and problem structuring activities are important parts in an overall Multiple Criteria Decision Analysis (MCDA)-process, as it to a high degree affects the outcome. To facilitate the process, the analyst often follows a method or process, e.g., Analytic Hierarchy Process (AHP), SMART, or an approach based on the ideas of Value Focused Thinking (VFT).

In VFT, the general idea is to first formulate the values and objectives of a preferred solution and then based on these develop the alternatives. A method following this workflow is Morphological Analysis (MA), which is a general method for structuring various types of problems, both wicked and regular problems. MA divides the problem into a matrix where the columns describe dimensions deemed to be important, and the rows describe different states of the dimensions (compare to objectives and attribute levels). Then, a set of configurations (compare to alternatives) are defined, where one configuration is a combination of one or more states in each dimension.

In this research, we show how the problem structuring and alternative generation approach of MA can be combined with MCDA.

4 - Multicriteria Decision Analysis as Focus for Strategic Planning

Theodor Stewart

Many discussions of strategic planning are relatively qualitative in nature, and say little about the role of analytical support. Useful discussion of the structure of the strategic planning process is provided by Simon and Mintzberg, and we shall focus particularly on the three phases identified by Mintzberg, namely (a) Identification, (b) Development and (c) Selection. A naïve view may be that the domain of Multicriteria Decision Analysis Analysis (MCDA) is restricted to the third (selection) phase, but this view is challenged. Analytic support to the first two phases might well be provided by "soft" OR, or Problem Structuring Methods (PSMs) preliminary to MCDA. We have however previously argued that MCDA itself can act as, and be utilized as, a PSM in the full sense of the expression, so that MCDA as a potentially integrating role throughout.

In this presentation, we unpack the forms of MCDA techniques and approaches that can provide support for each of the three Mintzberg phases. These are represented in a diagram demonstrating the inherent feedback nature of the process and the interacting nature of the MCDA interventions. The process is illustrated by a simplified example drawn from a real world context in water resources planning.

■ TC-39

Tuesday, 12:30-14:00 - Q014

Project Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Mario Vanhoucke*
Chair: *Annelies Martens*

1 - Focus on the breadth and depth of skills in the MSR-CPSP

Jakob Snauwaert, Mario Vanhoucke

This paper addresses a multi-skilled extension of the well-known resource constrained project scheduling problem (RCPSP). Although a handful of papers already dealt with the multi-skilled RCPSP (MSR-CPSP), little to no attention is given to the ideal levels of skills for the multi-skilled resources. In this paper, skills are measured along two dimensions: breadth and depth. In a project environment, the breadth of a resource is perceived as the amount of skills an employee masters and is a way to measure the flexibility of the resource. The depth is the efficiency or skill level with which a resource can perform a skill. The MSRCPSP with breadth and depth consists of scheduling activities with skill requirements and assigning multi-skilled resources to those activities. Using the created schedules and assignments, the best workforce composition is analysed. A key aspect in this analysis is the trade-off between breadth and depth.

To be able to efficiently solve the MSRCPSP, a hybrid genetic algorithm is created. This problem- specific procedure combines a new representation as well as new crossovers and tailor-made local searches. A computational experiment measures the impact of the different multi-skilled resources and their efficiency levels on the makespan and resource idleness of the project. Additionally, the cost of resources is used to compare the various composed workforces.

2 - A Priority Rule Comes from the Regression Analysis

Jingyu Luo, Mario Vanhoucke, José Coelho

Priority rule-based scheduling is a widely used heuristic approach to solve the resource-constrained project scheduling problem (RCPSP). In the literature, it is known that the project network and resource characteristics have a significant impact on the performance of these priority rules. This study aims at analyzing the performance of priority rules and compare this with best known solutions. In doing so, a linear regression based approach will be used to create understanding in the performance of these priority rules, and experiments on a large dataset will enable us to improve these priority rules to find better solutions. Results show that this so-called regression-based priority rule can outperform most of the classic priority rules and can solve some projects to the best-known solution for instances for which the classic rules could not provide such an optimal solution.

3 - An exact solution procedure for integrating demand planning in staff scheduling problems

Mick Van Den Eeckhout, Mario Vanhoucke, Broos Maenhout

In staff scheduling problems, the staffing composition is determined and a personnel roster is constructed in order to cover the fixed staffing requirements represented by a demand pattern. The personnel roster consists of individual lines-of-work, called personnel patterns, consisting of days-on and days-off assignments upon which different counter and time-related constraints are imposed. In this research, we integrate demand planning in the staff scheduling problem by simultaneously deciding on the personnel roster and the staffing requirements. The demand pattern stems from a project scheduling problem with discrete time/resource trade-offs, meaning that different execution modes exist for each activity. The project scheduling constraints (e.g. precedence constraints) are imposed on the corresponding demand pattern. The main principle of the proposed solution procedure is the decomposition of the strategic problem definition into multiple tactical subproblems. For each tactical subproblem, the staffing composition is postulated a priori and a feasible personnel roster is pursued which is able to cover the workload stemming from a project schedule. As a result of this decomposition, personnel availability information can be included while determining a demand pattern by including cuts in the project scheduling problem. The computational experiments showed that both the decomposition and the addition of the cuts are required to obtain a well performing algorithm.

4 - Automatic detection of the best performance priority rule for resource-constrained project scheduling problem

Weikang Guo, Mario Vanhoucke, José Coelho

Priority rules are applied in many commercial software tools for project management because of their known advantages like ease of implementation, very intuitive and very fast. However, some priority rules give poor quality solutions. If one wants to find the best performance priority rule for a project instance, each priority rule must be tested on the project. As the number of project nodes increases, this will take quite some time. This paper proposes a new method for classifying and locating the best priority rule for non-preemptive resource-constrained project scheduling problem (RCPSP) through machine learning classification techniques. The objective is to find the most appropriate priority rule that minimizes the total makespan of the project without violating the precedence and resource constraints. This paper (1) focus on various supervised machine learning classification techniques to select the best priority rule for minimizing the total makespan; (2) conducts a comparative study of the performance of different classification models on real-world project data; (3) utilizes multiple attributes to discover the correct and easiest way to sort, rank, analyze and evaluate the alternative solutions. Experimental results show that our classification model can adapt to the task very well and reach an accuracy of 91.4%. This indicates that our classification model is effective and reliable given a project instance.

■ TC-40

Tuesday, 12:30-14:00 - Q015

Vehicle Routing with Drones

Stream: Vehicle Routing and Logistics Optimization II
Invited session
Chair: Claudio Sterle

1 - Mission and Path Planning for Unmanned Aerial Vehicles

Armin Fügenschuh, Daniel Müllenstedt, Johannes Schmidt

The mission and path planning problem for an inhomogeneous fleet of unmanned aerial vehicles (UAVs) asks for optimal trajectories that together visit a largest possible subsets from a list of desired targets. When selected, each target must be traversed within a certain maximal distance and within a certain time interval. The UAVs differ with respect to their sensor properties, speeds, and operating ranges. If the targets are surrounded by radar surveillance, then the UAVs' trajectories should be chosen to avoid these forbidden areas. In contrast to classical vehicle routing problems with time windows, this problems allows for free-flight routes which are not bound to street-like networks. Additionally, the fuel consumption rates during cruise (at various speed and altitude levels), climb and descend are crucial and thus need to be considered within the model. We formulate the mission and path planning problem for UAVs as mixed-integer nonlinear control problem, and apply discretization and linearization strategies to obtain a mixed-integer linear programming problem which can be solved numerically using available software tools. We discuss the applicability of this approach with respect to the number of potential targets, the fleet size, and the number of restricted areas.

2 - The Minimal Makespan Vehicle Routing Problem with Drones: A Matheuristic Approach

Daniel Schermer, Mahdi Moeini, Oliver Wendt

Drones have started to play an increasing role in both, academic research and practical context and are gradually becoming a proven technology. In this work, we are interested in studying the Vehicle Routing Problem with Drones (VRPD). Given a fleet of vehicles that are equipped with sets of drones, the objective consists in designing feasible routes and drone operations such that all customers are served and minimal makespan is achieved. We formulate the VRPD as a Mixed Integer Linear Program (MILP) that can be tackled by any standard MILP solver. Moreover, we introduce several sets of valid inequalities. Due to limited performance of the solvers in addressing larger instances, we propose a matheuristic approach that effectively exploits the problem structure of the VRPD. Integral to this heuristic approach, we propose the Drone Assignment and Scheduling Problem (DASP) that, given an existing routing of vehicles, looks for an optimal assignment and schedule of drones such that minimal makespan is achieved. In order to evaluate the performance of a state-of-the-art solver in tackling the MILP formulation of the VRPD, the benefit of the proposed VIEQs, and the performance of the matheuristic, we carried out extensive computational experiments. According to the numerical results, the use of drones can significantly reduce the completion time and the proposed VIEQ as well as the matheuristic have a significant contribution in solving the VRPD effectively.

3 - The Traveling Salesman Problem with Drone Re-Supply

Michael Dienstknecht, Nils Boysen, Dirk Briskorn

With increasing population density and traffic in our cities on the one hand and a highly competitive market in e-commerce requiring rapid delivery on the other hand, new logistic concepts have to be developed in order to satisfy customers while still being cost-efficient. Such concepts often rely on new technologies like drones or robots either operating on their own or cooperating with traditional equipment like trucks. We focus on a cooperation of a single truck and a drone. There is a given set of customers each of them having a single demand of standard-size. Demands are delivered by a capacitated truck starting from a depot. Due to its limited capacity the truck cannot carry all demands when leaving the depot. Instead of returning to the depot in order to pick up more demands the truck may be re-supplied by a drone operating from the depot which can deliver one demand unit per flight. Such re-supplies may only be delivered to the truck while waiting at a customer. Thus, truck and drone operations have to be coordinated. Operating the truck is charged with a cost for driving and waiting, each drone flight is charged with a cost, as well. The objective is to find a truck route and a drone schedule of minimum total cost so that truck and drone operations are coordinated and each customer is served. The problem is formulated as a MIP and a non-exact decomposition approach is developed. A comparison of the novel concept with the traditional one is provided.

4 - A new MILP formulation and heuristic approach for the flying sidekick TSP

Claudio Sterle, Maurizio Boccia, Adriano Masone, Antonio Sforza

In recent years the usage of unmanned aerial vehicles (UAV) in different fields, such as surveillance, disaster management and transportation , is significantly increasing and new decision problems are arising and are worth to be investigated. In this work we focus on the usage of UAV in the last-mile distribution. The flying sidekick traveling salesman problem (FS-TSP) is a drone assisted parcel delivery problem aimed at defining the distribution plan of a driver-operated truck assisted by an unmanned aerial vehicle. The objective is the minimization of the time required to service all the customers, taking into account UAV payload capacity, battery and distance constraints. The truck and the UAV may must depart and return to a single depot, either in tandem or independently. Several models have been proposed in literature to formulate the FS-TSP, but none of them is actually used, not even on small instances, because of their huge dimensions and complexity. We propose a new more compact mixed integer linear programming formulation for the problem, strengthened by several additional valid inequalities integrated in a branch-and-cut algorithm. Moreover, a heuristic approach to deal with larger instances is also presented. The proposed exact and heuristic methods are tested on several instances and compared with other approaches present in literature, showing good results in terms both of the quality of the solution and computation time.

■ TC-41

Tuesday, 12:30-14:00 - Q013

Service locations and stations

Stream: Public Transportation I
Invited session
Chair: *Marjan van den Akker*

1 - Optimizing bus line platform assignment across bus stations in Utrecht
Wouter ten Bosch, Han Hoogeveen, Marcel van Kooten Niekerk

In Utrecht the central transit hub consists of several separate bus stations. This raises the problem of distributing the bus lines over the bus stations; the goal is to minimize the total travel time for all passengers, who want to transfer at the hub. Here we are not allowed to adjust the current timetable, and we have to take the capacity and vehicle limitations into account.

To find out which journeys are made daily and by how many people we use data from a digital fare system. This results in passenger groups, and for each group, we compute the relevant travel options given the current timetable. The routes are split into an inbound itinerary, a transfer within the same bus station, and an outbound itinerary; the validity of a travel option depends on the assignment.

We decompose the problem into first finding a distribution of the lines over the stations and then assigning them to a platform at the station of choice. In the first subproblem, we find the best set of transfers using Integer Linear Programming, resulting in a station assignment. In the second subproblem, for each station, we distribute the bus lines over the platforms. In this subproblem, there can be multiple lines assigned to a single platform, as long as there are never more vehicles at the platform simultaneously than physically fits. The primary goal is to maximize comfort of the transfer passengers by assigning tight transfers to adjacent platforms; this problem is solved using ILP as well.

2 - An Iterative Cut Separation Approach for the Rolling Stock Rotation Problem with Maintenance Constraints
Boris Grimm, Thomas Schlechte, Markus Reuther, Ralf Borndörfer

For operating a railway company the company's railway rolling stock is one if not the most important ingredient.It decides about the number of passenger or cargo trips the company can offer, about the quality a passenger experiences the train ride and it is often related to the image of the company itself. Thus, it is highly desired to have the available rolling stock in the best shape possible. Moreover, in many countries, as Germany where our industrial partner DB Fernverkehr AG (DBF) is located, laws enforce regular vehicle inspections to ensure the safety of the passengers. This leads to rolling stock optimization problems with included vehicle maintenance. This problem is well studied in the literature see Maroti and Kroon 2005, 2007 or Cordeau et al., 2001 for applications including vehicle maintenance. We focus on a new algorithmic approach to solve the Rolling Stock Rotation Problem for the ICE high-speed train fleet of DBF with included vehicle maintenance. It is based on a relaxation of a mixed integer linear programming model with an iterative cut generation to enforce the feasibility of a solution of the relaxation in the solution space of the original problem. The MILP model is based on a hypergraph approach presented in Borndoerfer et al., 2016. The new approach is tested on real world instances and compared to an other approach that is in operation at DBF.

3 - Finding robust shunting plans
Marjan van den Akker, Roel van den Broek, Han Hoogeveen

The Netherlands Railways (NS), the largest Dutch passenger railway operator, uses only a subset of the available trains during off peak hours to operate the timetable. The surplus of rolling stock is parked at shunting yards, where the trains are cleaned and small maintenance activities take place. To efficiently operate shunting yards, shunting plans are created to schedule the cleaning, maintenance and train movement activities such that all service activities of each train are completed before its scheduled departure. However during execution of the plan, disturbances occur that cause deviations in the duration, release date or deadline of activities.

Therefore plans have to be robust, i.e., capable of absorbing the disturbances without a large deterioration of the solution quality. Due to the complexity of computing the robustness of a schedule directly, many surrogate robustness measures have been proposed in literature. In this work, we propose new robustness measures, and compare these with several existing measures. Moreover, we compare the measures with the results of a simulation study to determine which measures provide good approximations of the true robustness of a shunting plan. We incorporate the most successful robustness measures in a local search algorithm to compute plans that are both efficient and robust. Our computational experiments are performed on real-world instances from shunting yards of the Netherlands Railways (NS).

■ TC-42

Tuesday, 12:30-14:00 - Q113

OR application for MaaS II

Stream: Transportation
Invited session
Chair: *Caterina Malandri*

1 - The efficiency of bus rapid transit (BRT) systems: a dynamic congestion approach
Fernando Feres, Leonardo Basso, Hugo Silva

The penetration of Bus Rapid Transit (BRT) systems has been increasing fast, mostly because of the promise of better, faster and cheaper public transport at a fraction of what a subway or heavy rail would cost. While mostly successful, there have been many reports of excess demand for the systems, in the form of heavy queuing to board the buses. We propose a dynamic congestion model that endogenously model queuing both on the road and at BRT stations, which are the center of our interest. We show that implementing a BRT can induce a Pareto Improvement: both users' time cost and public transport cost decrease. Importantly, this better situation -which provides strong support for the observed BRT surge- will have more boarding delays, i.e., longer queues at bus stops, than the equilibrium when buses run in mixed traffic.

2 - Solving a Real-World Vehicle Routing Problem with Pick-up and Delivery Time Windows for an Austrian Mobility Provider
Veronika Pachatz, Philipp Hungerländer, Kerstin Maier

The Vehicle Routing Problem with Pick-up and Delivery Time Windows (VRPDTW) is concerned with finding minimal tours for vehicles that pick-up and drop-off customers within their desired time window, while respecting the maximal capacity of each vehicle. In this work, we consider a real-world VRPDTW for ISTMobil, an Austrian Mobility Provider. ISTMobil focuses on rural regions that suffer from insufficient public transportation and offers a new, sustainable form of mobility that is flexible and individual, but also inexpensive. Besides picking-up and dropping-off customers at defined assembly points within their requested time windows, ISTMobil also provides school transport and transport for doctoral visits. The vehicle fleet consists of cars and minibuses, which are used for example for school transports. In addition there are several vehicles, which allow to transport oversize luggage or handicapped persons. Depending on the respective customers the appropriate vehicle must be assigned for the pick-up.

We propose a Mixed-Integer Linear Programming approach as well as a heuristic based on a Large Neighborhood Search for solving the ISTMobil VRPPDTW. In a computational study we demonstrate the efficiency of our exact and heuristic approaches on a great variety of benchmark instances, which are based on real data.

3 - A demand responsive transport system for people with disabilities
Alessio Salvatore, Pasquale Carotenuto, Massimiliano Gastaldi, Giulia Gaita, Riccardo Rossi

In recent years, several studies focused on operating techniques and models with the aim of reducing traffic, improving public transport and ensuring an accessible transport system for disabled people have been carried out. Mobility as a Services (MaaS) concept fulfils this requirement; indeed, it tries to simplify people's mobility combining different transport models to offer a multi-modal travel option using information and communication technologies. This work propones a pilot study on a demand responsive transport system (DRTS) for movement in the first and last mile of people with disabilities. An applicative software for managing dial-a-ride (DARP) has been developed; it includes the following features: different starting point for fleet vehicles; possibility to handle heterogeneous fleet of vehicles and different types of users; possibility to manage time-variable capacity during service, depending on disability served. Moreover, it processes the users' requests sequentially, answering to them in real-time. Tests have been carried out using the recorded requests history with different configurations of vehicles fleet; the early results have been very encouraging, indeed in just few seconds the daily operational plan for all the fleet can be determined.

4 - Public transport network vulnerability and unbalanced travellers' delay distribution
Caterina Malandri, Luca Mantecchini, Filippo Paganelli, Maria Nadia Postorino

Public transport network vulnerability refers to performance losses caused by unexpected disturbances such as natural disasters or technical failures. Degraded networks show a decrease in connectivity, delays propagation and routing problems. Transport network disruptions cause significant impacts, included financial losses, on several actors, from travellers to transport service providers. Then, vulnerability has now emerged as a noteworthy topic and, in the last years, several approaches have been proposed to quantify it. This paper proposes a novel approach to evaluate delay concentration in public transport network in disrupted conditions by using a Lorenz curve approach. In other words, there could be an unbalanced distribution of delays over travellers. The approach adopted is remarkably powerful at a twofold level. First, it allows to evaluate whether negative consequences are evenly spread among passengers or, conversely, if disparities exist. Second, the distribution of delays among users is summarized by a single index (Gini Coefficient). The modelling approach is able to capture transit system dynamics and travel decisions of individual passengers in response to network disruptions. The proposed approach, tested on the public transport system of a large urban area for different disrupted scenarios, can help public transport managers to define strategies for reducing impacts due to unplanned failures, thus reducing costs for both passengers and transport operators.

■ TC-43

Tuesday, 12:30-14:00 - Q114

Facility location II

Stream: Location Analysis and Optimization
Invited session
Chair: *Víctor Blanco*

1 - A Multi-facility Location Problem with Regional Demand Entities
Nazlı Dolu

We consider a multi-facility location problem where facilities are points in the plane and demand entities are non-convex regions. We aim to locate a given number of facilities and assign each demand entity to a single facility so as to minimize the maximum of the distances between the entities and the assigned facilities, where the distance between a facility and an entity is measured by the minimum distance. We formulate the problem as a mixed-integer second order cone programming problem and to come up with a solution for this problem, an algorithm is created which mainly consists of two parts; clustering the customers with a heuristic algorithm and then locating a facility to each of the clusters with a binary search algorithm. In the end, we compare the performance of the algorithm with the optimal solutions both in terms of time and quality.

2 - 3D Location-Allocation Problem of Drone Base Stations in Next Generation Wireless Networks
Cihan Tugrul Cicek, Hakan Gultekin, Bulent Tavli

In this study, a novel location-allocation problem that determines 3D coordinates of Drone Base Stations (DBSs) together with resource allocation in a wireless network is developed. A novel Mixed Integer Non-Linear Programming (MINLP) formulation is developed, where the objective is to maximize the total profit of provided wireless services such that all users are ensured to be served by a single DBS with a minimum service level threshold and both resource and service capacity of DBSs are not violated. The service function is typically a non-convex function of both the distance and allocated resource in such wireless networks. To improve the computational performance, a convex Non-Linear Programming (NLP) formulation as a relaxation to MINLP is developed by exploiting some features of this service function. Furthermore, a heuristic algorithm in which the location and allocation sub-problems are alternately solved is developed to efficiently solve large scale problems. Due to lack of benchmark data, a synthetic data set is generated, and a broad computational study is performed. Simulation results show that our heuristic outperforms in terms of CPU times and generates promising results in reasonable times. Based on the results, we also provide several managerial aspects for organizations in telecommunication industry to further improve the use of DBSs.

3 - Heuristic Aggregation Framework to Address Source Errors in Large Discrete Location Problems
Carolina Castañeda P., Daniel Serra

Demand aggregation induce errors in the solution when solving location problems because these are approximated models where the solution is optimal for the aggregated data but not necessarily for the non-aggregated data. Source errors are caused mainly by the loss of information when real demand is replaced by aggregated points, often represented by the centroid of a polygon that depicts a geographical region. Also, analysts induce errors when they prepare and make spatial analysis of data. We propose a framework that integrates the solution method of large discrete location problems with heuristic methods to address source errors. First, we obtain an initial aggregation making groups of the original demand. Then, we find groups' centroids through the central point of a minimum spanning tree. These centroids become the aggregated demand for a location model solved with a simple heuristic. We also repair the solution reallocating real demand points that were wrongly assigned to the open facilities. Based on that, we make a perturbation of the current aggregation and iteratively find new aggregations and their centroids until the improvement in the location model's solution is not significant. After the first iteration, a GRASP is integrated into the aggregation algorithm to obtain a new set of groups. Finally, we solve the location model with an exact or metaheuristic method, according to the size of the instance, to obtain the best solution with the suitable aggregation.

4 - A two-stage stochastic formulation for the simple plant location problem with order
Xavier Cabezas, Sergio García Quiles

The simple plant location problem with order (SPLPO) is a variant of the simple plant location problem (SPLP) where the customers have preferences on the facilities that will serve them. The problem can be formulated as a mixed integer linear program (MILP) and some results about its strength can be found in the literature. In this paper we present a two-stage stochastic formulation for SPLPO where the preferences given by the costumers are considered random vectors. Furthermore, we carried out an experimental study to solve some instances by using a semi-Lagrangean relaxation methodology that exploits this structure.

■ TC-44

Tuesday, 12:30-14:00 - Q115

AHP Theory

Stream: Analytic Hierarchy Process
Invited session
Chair: Werner Toth

1 - Identification of groups with homogeneous preferences through bayesian stochastic ahp
Pilar Gargallo, Alfredo Altuzarra, José María Moreno-jimenez, Manuel Salvador

Usually, in multicriteria decision problems with multiple actors, the number of decision makers is high and there is a great diversity of opinions. For this reason, and in order to elaborate decision proposals with the greatest possible degree of agreement, it is interesting to identify groups of decision makers with homogeneous priorities. In this work, a stochastic search algorithm for the identification of these groups through Bayesian AHP is proposed. The algorithm is based on clustering techniques and uses different ways of measuring the compatibility of the priorities of a decision maker with the priorities of a group. The proposed methodology is illustrated by a real case.

2 - An integrated constrained fuzzy stochastic AHP method for overcoming the choice problem in group decision making under uncertainty
Fernando Sitorus, Jan Cilliers, Pablo Brito-Parada

The Analytical Hierarchy Process (AHP) has been successfully applied to many multiple criteria decision making (MCDM) problems. However, AHP is often unable to fully address problems when the input data are difficult to be defined precisely and obtained from multiple decision makers (DMs). This work proposes an integrated constrained fuzzy stochastic AHP (IC-FSAHP) method in order to overcome such drawbacks. IC-FSAHP combines two existing constrained fuzzy AHP (FAHP) methods and further extends their applicability by means of stochastic simulations. In order to showcase the applicability of IC-FSAHP in a real MCDM problem, a case study for equipment selection was considered; the outcomes showed that IC-FSAHP is able to capture the multiple DMs' opinions and minimises the uncertainty associated with the imprecise input data. The effect of the number of DMs on rank discrimination is examined. In addition, the occurrence of rank reversal has been assessed and it is shown that the ranking was not affected by changes in the number of alternatives. Moreover, by comparing the difference of uncertainty in fuzzy overall scores obtained using IC-FSAHP to that obtained using an existing FSAHP method, it is demonstrated that our proposed method is capable of minimising the overestimation of fuzzy results. In conclusion, we show that IC-FSAHP offers a robust methodology to decrease uncertainty and increase the reliability of decisions taken by multiple DMs under uncertainty.

3 - A comprehensive uncertainty analysis of the analytic hierarchy process methodology applied in the context of environmental decision making
Werner Toth, Harald Vacik

An overview of uncertainty issues associated with the analytic hierarchy process (AHP) is provided. Further, an explicit understanding of uncertainty (designation, categorization, and quantification) with respect to the methodological properties of the AHP is developed and used to analyse a hypothetical group decision problem located in the context of environmental decision making (EDM). To calculate the numerical impact of especially designed uncertainty scenarios (USs) on the final ranking given by the AHP, a simulation experiment is conducted using R. It evaluates the impact of uncertainty within three variants of a hypothetical decision-making case by calculating an "overall uncertainty" measure. The consideration of uncertainty may lead to a rank reversal in comparison with that analysis neglecting uncertainty (best alternative given by the AHP). The results show that the absolute maximal impact caused by an US is approximately 0.03. With respect to a single US and the specific case characteristics, in about 50% of the simulated runs a rank reversal occurs. From a theoretical normative point of view, the effects of considering uncertainty issues in the AHP methodology cannot satisfy the ideal of a rational decision analysis. From a descriptive point of view, considering the practice of decision makers, the impacts of the considered uncertainties stay within reasonable limits, meaning that the maximal numerical impact stays on the hundredths decimal place.

■ TC-45

Tuesday, 12:30-14:00 - Q117

Air Transportation II

Stream: Transportation and Logistics
Invited session
Chair: Sakae Nagaoka

1 - An optimization method for airport terminal arrival route selection, runway assignment and aircraft trajectory integration.
Raúl de Celis, Adrián Barea, Luis Cadarso

Incoming air traffic in a given airport can be provided by a great diversity of air routes. However, airports comprise a limited number of runways. The reduction in the number of paths that aircraft can transit takes place in terminal arrival routes, which act as an interface between incoming routes and approach trajectories. This occurrence entails that air traffic has to be carefully managed in terminal arrival routes in order to prevent possible bottlenecks. This work presents an optimisation model that manages not only approach and landing operations, but also terminal arrival routes, deciding on runway assignment, terminal arrival route selection and aircraft trajectory. The proposed integrated model leads to a mixed integer non-linear problem. For its resolution, a Benders decomposition is proposed. On the one hand, the master model deals with runway assignment and terminal arrival route selection, making use of a set of binary variables. On the other hand, the sub-model deals with the trajectory calculation problem, managing a set of continuous variables and minimizing a combination of fuel consumption and delay.

2 - Analyses on Error Propagation Characteristics of a Mathematical Model for Estimating Air Traffic Control Difficulty
Sakae Nagaoka, Mark Brown, Daniel Delahaye

Modernization of air traffic management systems is accelerating shifts towards trajectory-based and performance-based flight operations. These require performance indices such as safety, efficiency, and complexity. Air traffic controllers manage airspaces to provide safe separations between aircraft and to maintain orderly traffic flow, and the airspace capacity depends on factors associated with air traffic control (ATC) difficulty such as workload and traffic complexity. To design airspace/operational procedures, a performance measure for estimating ATC difficulty is desired. We have proposed a mathematical model of a difficulty index and aim to develop a difficulty mitigating algorithm for use in a controller support tool. This index utilizes the relative positions and velocities of pairs of aircraft as inputs and considers proximity using an objective function based on a kind of four-dimensional distance. The metric is used to calculate a difficulty value for a given traffic situation which is compared with a threshold to detect "difficult" situations. The input data include uncertainties such as estimation errors, and their effects on the estimated difficulty values are of concern to mitigate against two kinds of detection error: missed-detection and false-detection. Therefore, analyses on the effects of errors in the input data were carried out. This presentation briefly describes the method and some examples of the results.

3 - A branch-and-bound algorithm for airport gate assignment problem
Kerem Alanlı, Ozlem Karsu, Meral Azizoglu

In this study, we consider an airport gate assignment problem, in which a pre-specified number of flights are assigned to a set of gates. The flights that cannot be assigned to any gate due to overlaps are directed to an apron. Our objective is to minimize total walking distance travelled by all passengers. We formulate the problem as a mixed-integer nonlinear programming model and then linearize it. We develop a branch-and-bound algorithm that employs powerful bounding mechanisms. The results of our computational experiment show that the mathematical model can handle small sized problem instances, while the branch-and-bound solves relatively larger instances in reasonable time.

■ TC-46

Tuesday, 12:30-14:00 - L243

Decision Making under Imprecise Information

Stream: Decision Making under Imprecise and Vague Information
Invited session
Chair: Barbara Vantaggi

1 - On the elicitation of outer approximations of a coherent lower probability
Enrique Miranda, Ignacio Montes, Paolo Vicig

When modelling imprecise or vague information about the outcome of an experiment, one possibility is to consider a set of probability distributions instead of electing a single one without sufficient guarantees. Such a set may be equivalently represented as a coherent lower prevision, by means of lower envelopes. While this representation is computationally simpler, it still has a number of drawbacks: for instance, the number of extreme points of the set of probability distributions may be infinite, and these may be difficult to characterise.

For this reason, it may be interesting in some cases to consider an outer approximation of a coherent lower probability or a prevision by means of a model that is simpler to handle. In the past, we have considered the cases of 2-monotone capacities, belief functions and possibility measures, amongst others. However, the choice between the possible outer approximations is not straightforward. One possible criterion is to focus on those outer approximations that minimize the loss of information in some sense. While this can be measured by means of some distance, it does not suffice in general to determine a unique solution.

In this paper, we investigate this problem and compare a number of strategies to ease the elicitation among the outer approximations: preservation of partial preferences, lexicographic orders between distances, similarity measures or imprecise entropies, amongst others.

2 - Ambiguity Aversion: Models and Testing
Radim Jirousek, Vaclav Kratochvil

The paper describes results from the behavioral experiments designed to test new normative decision models exhibiting the same ambiguity aversion as human decision makers. The novelty of the models stems from the idea that the ambiguity aversion reduces the subjective probabilities of decision-makers in the way that eventually they do not compute their subjective expected utility (SEU) using a subjective probability as assumed in Savage's SEU approach. Instead, they use just a reduced subjective capacity function, which is superadditive, and which generally does not sum up to one. The higher the ambiguity, the greater the reduction and therefore also the lower the expected utility.

To find a proper subjective capacity function we use the following approach: The decision situation is described with the help of a belief function, from which the required capacity function is derived in two steps. The first step realizes the pignistic transform that was strongly advocated for decision making by Philippe Smets. In the second step, this probability function is reduced in dependence on the level of ambiguity aversion of the considered decision maker, and on the amount of ambiguity in the considered situation (the state of the considered universe). For this, the model is equipped with a subjective parameter of ambiguity aversion. Its value (from the unit interval) can be experimentally established for each decision maker.

3 - Decisions on generalized Anscombe-Aumann acts under possibly unexpected scenarios
Davide Petturiti, Giulianella Coletti, Barbara Vantaggi

We consider decisions on generalized Anscombe-Aumann acts, mapping states of the world to belief functions over a set of consequences. Preference relations on these acts are given by a decision maker under different scenarios (conditioning events). Then, we provide a system of axioms which are necessary and sufficient for the representability of these "conditional preferences" through a conditional functional parametrized by a unique full conditional probability on the algebra of events and a cardinal utility function on consequences. The model is able to manage also "unexpected" (i.e., "null") conditioning events. We finally provide an elicitation procedure that reduces to a Quadratically Constrained Linear Problem (QCLP).

4 - A New Prediction Model for Customer Demands in the Automotive Industry
Ivan Djordjevic, Dobrila Petrovic

Suppliers in the automotive industry make production planning, raw material ordering, machine and warehouse capacity use, manpower planning and other resource planning due to customer demands. The precise prediction of customer demand and its fluctuation in the contemporary supply chain is extremely important in contemporary supply chains. Suppliers receive customer orders via electronic data interchange (EDI) that are uncertain until the shipment date. Customer orders contain two segments: just in time orders (JIT) and forecasted orders. A new model for customer demand prediction for a first tier supplier in the automotive industry is proposed. Fluctuation in customer demands is uncertain and modelled using fuzzy sets which are generated based on real-world data from the supplier's enterprise. The model is based on fuzzy linear regression. The equations in fuzzy regression are optimized using a fuzzified Simplex method. The range of different confidence level is used which should help the decision maker to choose the appropriate confidence level. The proposed model is tested on a real supplier's data for a period of two years. The customer demands are considered on a weekly level. The period in the first year is used for model construction and its validation is performed using the data in the second year period. The same database is used for prediction using clasical statistical methods. The results obtained by the proposed model and statistical methods are compared.

■ TC-47

Tuesday, 12:30-14:00 - L247

Behavioural issues in OR practice

Stream: Behavioural OR
Invited session
Chair: Götz Giering

1 - Enriched Soft System Methodology for practitioners
Fahad Mehmood, Hussain Syed Kazmi

Companies face many problems that are complex in nature and have high levels of uncertainty. Soft OR has been instrumental in addressing such situations and the idea of mixing hard and soft methods has been explored extensively in literature. Soft system methodology(SSM) is one of the most popular methods in soft OR. The soft system methodology, in our experience, is found not to follow a linear / sequential model but an iterative and concurrent model. We build upon the existing methodologies provided by Checkland & Tsouvalis (1997), and Castellini and Paucar-Caceres (2018) to form an enriched soft system methodology(ESSM). ESSM builds upon and adds to the existing soft system methodologies in two ways: (1) It posits that most of the stages in the SSM do not follow in reality a linear model. (2) it also posits that SSM stages are not necessarily sequential in nature, rather concurrent in nature. That means to say that (a) two stages are happening alongside and both feeding into each other resulting into a set of activities that are happening in a concurrent fashion rather than in a sequential manner b) after the completion of one stage the movement does not necessarily happen to the next stage specifically related to the outcome of the last stage, rather new ontological actions may start alongside the existing ontological actions in order to address the outcomes of the last stage, thus resulting into concurrent ontological actions to solve the problem.

2 - Adoption-based design of decision support tools for manufacturing environments
Melanie Ayre

Manufacturing is once more a growth sector in OECD economies. 20th century trends in off-shoring to lower-labour-cost countries have eased, with re-shoring increasingly popular. While the main drivers for this are in quality standards and bespoke products, the adoption of digital technologies that reduce the total cost of production while enabling customisation will be critical to its continuation.

We consider a case of high value, low volume manufacturing, with large crews and a complex relationship between tasks to be done and capability to perform the task. In schedule recovery scenarios, there are two important factors affecting the deployment of decision support software using combinatorial optimisation. Firstly, there is a large body of tacit knowledge, that experts lean on to solve the problem, which is challenging to encode, and based around historical completions of partial data. This requires a detailed situational awareness to be developed.Secondly, there are no genuine constraints in the problem space. As an example, a sufficient number of people can move a blocking object that theoretically requires a tug to be booked and scheduled.

In this paper, we present our approach to system design considering incomplete information, tacit knowledge gathering, and soft constraints, demonstrating the importance of socio-technical settings to the adoption of 'Industry 4.0' technologies in operational contexts.

3 - Do stakeholders know which wastewater systems achieve what they want?
Philipp Beutler, Judit Lienert

Centralized wastewater infrastructures are widely established, but aging. Communities need to reinvest into the expensive system or transition to other systems. Decentralized wastewater system innovations may be cheaper, more environmentally-friendly and efficient for some rural conditions, but are not well known. We can ask users: What do you expect from a wastewater system? Which one would you choose? Usually they choose the "status quo"; a system with sub-optimal performance. We postulate that carefully considering stakeholder values results in a strongly different choice than following the (biased) gut feeling. We applied multi-criteria decision analysis (MCDA) to tackle this environmental decision problem in a small Swiss case study that lacks budget and expertise. Following a value-driven approach, we included preferences of 19 stakeholders, elicited in face-to-face interviews, an online survey, and two workshops. Group discussions revealed a clear tendency to select a centralized system. Stakeholders justified their choice with lack of knowledge and their being used to today's system (availability bias). However, the elicited weights of local stakeholders were very similar, with high priority on environmental objectives. The MCDA of 50 alternatives revealed that decentral wastewater options achieve these stakeholder objectives best. Our experience indicates that MCDA is a valuable - and applicable - approach to support lay people in complex environmental decisions.

4 - Process tracing the choice quality in riskless multi-attribute decisions
Götz Giering, Gilberto Montibeller, L. Alberto Franco

Empirical findings from behavioural research suggest that individuals employ a range of strategies to construct their preferences when faced with multi-attribute choice problems. In this presentation, we report on an ongoing behavioural study that adopts a process-tracing approach to evaluate these preference construction processes in terms of quality. The study involves a set of hypothetical choice problems that vary in terms of linearity and attribute ranges, and employs findings about the range sensitivity bias as a normative benchmark to compare against observed decision processes. By doing so, this study goes beyond consistency checks and thus has the potential to identify, not only the occurrence of discrepancies between observed choice behaviour and the value model, but also the underlying causes that are connected to the attribute weighting stage. The study findings will enable the development of recommendations to improve decision-making processes in multi-attribute choice problems.

■ TC-48

Tuesday, 12:30-14:00 - L248

Energy Production and Distribution II

Stream: Applications of Dynamical Models
Invited session
Chair: *Jong Heon Lee*

1 - Quality of open data sets for intermittent energy production from the Nordic countries
Lars Hellemo, Marte Fodstad, Pernille Seljom

High quality and consistent input data is a prerequisite for trustworthy results from Energy models. For our models investigating the value and use of flexibility in the interaction between the Nordic energy markets and the European markets, we need data for intermittent energy production covering both the Nordic region and the rest of Europe.

Several open sources for production data based on satellite data and reanalysis are available, and we investigate how well the reported numbers match actual production data from wind parks and photovoltaic installations in the Nordic countries. Correlation between reported production factors, load durations, and seasonal variation are evaluated.

We consider data sources Renewables Ninja and EMHIRES, which are compared with available historic production data from the Nordic countries.

2 - A Goal Programming model with interval coefficients and target intervals for selection and planning of marine renewable energies in the UK
Negar Akbari, Dylan Jones

Marine renewable energies including offshore wind, wave and tidal power have gained much attention with respect to their significant potential for sustainable and green power production. However, these technologies are not all in the same level of maturity; while offshore wind power has had remarkable success in terms of technology, cost reduction, and capacity installation in the past few years, tidal stream and wave power have had a much lower advancement in these areas. In this seminar a goal programming model with interval coefficients and objectives is used to determine the optimal mix of marine renewable energies in the UK. The interval coefficients are used to take into account the impreciseness in the data and goals. A number of objectives including power production, proximity to population centers, environmental impact, and installation and operations and maintenance cost have been defined. This study will contribute to the literature on the application of goal programming in the marine renewable energy sector for helping decision (policy) makers in this domain.

3 - Optimization of demand side response programs and balancing services portfolio in an energy cluster
Mariusz Kaleta

We consider a micro-grid which is managed by the local system operator representing a local community and striving for system self-balancing. In such system, which is often referred to as energy cluster, the local system operator procures balancing services from local energy sources, demands and from wide area synchronous system (macro-grid) which is connected to. We formulate an optimization problem, in form of MILP, for balancing services portfolio management. The services can be provided by suppliers as well as consumers through various demand-side response programs or can be delivered from the macro-grid. All of these possibilities make the balancing services selection complex and the problem we formulated can be applied to support the local system operator in decision making process of shaping balancing services portfolio. We also present numerical results for some exemplary test cases.

4 - Optimizing Microgrid Operation Plan under Islanding Uncertainty
Jong Heon Lee, Siyoung Lee, Kyungsik Lee

In this talk, we consider the problem of optimizing microgrid operation plans in the context of uncertain islanding events. Significant financial losses can be caused if a microgrid does not cope well with the islanded operation, during which it is disconnected from the transmission system. We propose a multistage stochastic optimization model to optimize proactive policy that establishes an operation plan for each possible islanding scenario with the corresponding recourse decisions. In addition, an efficient algorithm based on the two-stage Benders' decomposition method is proposed to solve the large-scale mixed integer optimization model. Numerical experiments show that expected operation costs can be reduced with the proposed proactive policy compared with the responsive policies. It is also shown that the proposed decomposition algorithm can effectively solve large-scale problems which are hard to solve with an extensive formulation approach.

■ TC-49

Tuesday, 12:30-14:00 - L249

Software for large-scale optimization I

Stream: Software for Optimization
Invited session
Chair: Yasumi Ishibashi

1 - Parallel Numerical Algorithms for Structured Problems with PyNumero and Pyomo
Carl Laird, Bethany Nicholson, Jose Rodriguez

Emerging needs of science and engineering push the size and complexity of optimization problems. Many problem classes have inherent structure that can be exploited (e.g., time-domain discretization, multi-scenario optimization), however, there is a need for software frameworks that can allow rapid development of novel algorithms in high-level languages, while not sacrificing computational performance and parallel scalability.

The PyNumero package is an extension of Pyomo that provides a high-level framework for numerical algorithm development in a convenient Python package without sacrificing numerical performance. It includes high-level, linear algebra interfaces compatible with Numpy and Scipy, and HSL. In this presentation, we will show a Parallel-in-Time decomposition approach for dynamic optimization problems. In particular, the Pyomo.DAE framework is used to transform the dynamic optimization problem into a discretized set of algebraic equations. Then, we develop an NLP algorithm that can exploit the structure of these problems through parallel decomposition of scale-dependent linear algebra operations. Similar techniques have been implemented in C++ for optimization under uncertainty problems, and have shown very favorable parallel scalability (both strong and weak). However, PyNumero provides a high-level, rapid implementation path for development of novel algorithms that can address new structures while keeping the promise of strong numerical performance.

2 - LocalSolver 8.5: Introducing mathematical programming techniques inside LocalSolver
Julien Darlay

LocalSolver is an optimization solver based on heuristic search. It is designed to provide good solutions in short running time to any type of mathematical problem. This talk will introduce the new features of LocalSolver 8.5 released at the beginning of 2019. The main feature in LocalSolver 8.5 is the ability to compute lower bounds to prove optimality or to evaluate the quality of a solution. This lower bound is obtained by a reformulation of the initial model solved with enumerative technics and convex relaxations. The second major feature is the performance improvement for set-based models introduced in previous version. LocalSolver8.5 finds better solutions for routing problems (TSP, CVRP, Pickup and Delivery) and bin packing problems. As an example, the average gap on the CVRPlib instances goes from 5% in LocalSolver 8.0 to 1.6% in 8.5. For unordered set-model like bin packings problems, lower bounds are also computed using a dedicated MIP reformulation. LocalSolver 8.5 is an important step toward the integration of mathematical programming technics. LocalSolver 9.0 will continue in this direction with a better exploitation of convex relaxations and the usage of interior point algorithms for continuous optimization.

3 - HiGHS: a high-performance linear optimizer
Julian Hall

This talk will present HiGHS, a growing open-source repository of high-performance software for linear optimization based on award-winning computational techniques for the dual simplex method. The talk will give an insight into the work which has led to the creation of HiGHS and then set out the features which allows it to be used in a wide range of applications. Plans to extend the class of problems which can be solved using HiGHS will be set out.

4 - ParaNUOPT: Parallelization of NUOPT by using UG on cloud computing platform
Yasumi Ishibashi, Yuji Shinano

The Ubiquity Generator (UG) is a generic framework for parallelizing branch-and-bound-based solvers. ParaSCIP and ParaXpress, which have developed by using UG, solved open instances from MIPLIB on supercomputers that are high network throughput computing environments. However, any distributed parallel branch-and-bound solver by using UG on a low network throughput environment has not been reported. The distributed parallel branch-and-bound solver running on the low network throughput environment like a cloud computing platform helps business, since anyone can easily use it provided as a cloud service. Therefore, our goal is to develop a distributed parallel branch-and-bound solver that can run on a cloud computing platform effectively. For this goal, we have developed ParaNUOPT, which is a distributed memory parallelization of the commercial MIP solver NUOPT with UG. In this talk, we report computational results of ParaNUOPT running on the cloud computing platform.

■ TC-50

Tuesday, 12:30-14:00 - Mason Hayes & Curran

Developing the research agenda for SoftOR/PSMs

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: Robert Dyson

1 - OR for Public Policy Choice: the challenges
John Friend

OR has been slow to adapt to the distinctive challenges of public policy choice in a highly interdependent world; challenges which include the intrinsic difficulty of designing policies to match the diversity of the public interests typically to be reconciled, and the rich variety of local decision circumstances that might arise. A significant start in addressing these challenges was made as long ago as 1963, when the Nuffield Foundation agreed to underwrite a four-year project of Policy Research for Local Government, to be undertaken by an interdisciplinary team from the Institute for Operational Research, a newly formed joint enterprise of the UK Operational Research Society and the Tavistock Institute of Human Relations. This pioneering project led to a practical decision-focused philosophy of public policy planning as a continuous process of cross-boundary choice under the dual pressures of diverse sources of uncertainty - evidential, political and structural - and of insistent demands for early commitment. It also paved the way for programmes of work with UK government departments responsible for such policy fields as health and urban development, and for further fundamental research in the dynamics of inter-organisational policy change. Over the decades that followed, IOR's influence on policy practice and theory spread worldwide. This brief review will conclude by outlining some recent advances on which future practitioners and researchers can build.

2 - Organizational design in soft OR.
Chabane Mazri, Katherine Daniell, Alexis Tsoukias

SOFT OR/ PSM approaches have been instrumental in offering policy-makers with pragmatic tools and models allowing them to explore the increasingly complex and wicked issues they are facing. Moreover, it offered the opportunity to deploy more inclusive frameworks allowing to go beyond the analyst-decisionmaker duet to consider stakeholders contributions. In doing so, the roles of the analyst moved from the mastering of OR models to the facilitation of extended interactions. If the roles of models' master and facilitator have been well recognized and discussed in OR literature, we believe that there is an additional role devoted to the analyst that remains tacit despite its central importance. Indeed, by defining who participates and when in the decision process, the analyst conceives the temporary organization that will host the decision process making him an organization designer. From a constructivist standpoint, it is easy to see the extent to which such an organization will influence the terms of interactions and finally the decision process outcomes. Accordingly, this presentation ambitions to build the case for a better consideration of this role by further analyzing its influence on the decision process and suggesting a theoretical formalization of its practice

3 - Surveying the fields of Application of Strategic Options Development and Analysis (SODA) from 1989 to 2018
Leila Abuabara, Alberto Paucar-Caceres

Strategic Options Development and Analysis (SODA) is a well-established problem structuring method (PSM) that has been addressing problematic situation of shared concern for at least 30 years within the discipline of Operational Research (OR). SODA is an approach designed to help OR consultants and their clients with messy problems. Developed by Colin Eden, SODA uses interviews and documents to elicit thoughts and visually structure them by cognitive mapping. Group maps constructed through the aggregation of individual cognitive maps are used to facilitate negotiation about goals, key strategic issues, and options. The purpose of this paper is to survey SODA applications over the last three decades. Starting in 1989, the publication of the first collection of PSMs featured in the book 'Rational Analysis for a Problematic World', we survey articles published from 1989 to 2018. We examine: level of each application, whether as a direct and solely SODA or a hybrid approach; which elements of the methodology are more widely used; and in which parts of the world SODA has been applied. Our results suggest that SODA action-research has been used extensively to improve other methodologies through the hybrid use. Our analysis of 250+ papers surveyed suggest that SODA has been successful in improving the modelling process of the problematic situation helping to provide a common understanding to participants, its success in group negotiation support deserves further investigation.

4 - Exploring the soft skills of the CAP / OR professional - from the perspective of hard OR practice
Frances O'Brien

INFORMS describes its Certified Analytics Professional program as being focused on seven domains of analytics process: 1. Business problem framing 2. Analytics problem framing 3. Data 4. Methodology 5. Model building 6. Deployment 7. Lifecycle management This research explores how published case studies of hard OR/analytics practice report the first two 'framing' domains of the analytics process. Specifically, it reviews a selection of cases published in the Interfaces journal, describing practical analytics/OR applications. The research considers potential research directions including possible links between the framing domains and soft OR/PSM approaches.

■ TC-51

Tuesday, 12:30-14:00 - William Fry

Optimal Control Applications 3

Stream: Optimal Control Theory and Applications
Invited session
Chair: Stefan Wrzaczek

1 - Optimal Control and the Value of Information for a Stochastic Epidemiological SIS-Model
Raimund Kovacevic, Peter Grandits, Vladimir Veliov

We analyze a continuous time stochastic SIS epidemiological model, describing the transmission dynamics of infectious diseases where infected individuals can become susceptible again after recovery. The infectivity period of infected individuals can be influenced dynamically by a decision maker, with the aim to minimize the expected aggregated economic costs due to illness and drug treatment. This stochastic control problem is investigated under two alternative assumptions about the information available. If a complete and exact measurement of the size of the infected population is available at any time, then the optimal control is sought in a state-feedback form and the related Hamilton-Jacobi-Bellman (HJB) equation can be used. If no state measurement is available, then the optimal control is sought in an open-loop form and the problem can be reformulated as an optimal control problem for the Kolmogorov forward equation. In both cases, deriving optimality conditions requires non-standard arguments due to the degeneracy of the involved HJB and Kolmogorov equations. Based on the obtained theoretical results, the role of the information pattern is numerically investigated.

2 - Transmission dynamics and optimal control of Ebola virus
Amira Rachah

Ebola virus is a virulent pathogen for humans. The recent outbreaks of Ebola virus infections have underlined the impact of the virus as a major threat for human health. The virus attacks healthy cells and replicates itself in a host's body. It has recently affected several African countries. The early symptoms of the virus include a sudden onset of fever and intense weakness. Over time, symptoms become increasingly severe and include raised rash, internal and external bleeding. As the virus spreads through the body, it damages the immune system. Human-to-human transmission can take place with direct contact with blood or body fluids of a person who is sick with or has died from Ebola. It is also transmitted indirectly via exposure to objects or environment contaminated with infected secretions.

Mathematical modelling and optimal control theory have a powerful tool for investigating human infectious diseases, contributing to the understanding of the dynamics of diseases, providing useful predictions about the potential transmission of the virus and the effectiveness of possible control measures which can provide valuable information for public health policy makers.

In this work, we focus on the modelling and control of Ebola virus dynamics including demographic effects, latent undetectable and detectable compartments with isolation of infectious individuals. The aim of the control study is to minimize the number of infected individual and the cost of isolation program.

3 - Life-cycle behaviour in the face of large shocks to health
Michael Freiberger, Michael Kuhn, Stefan Wrzaczek

The majority of models describing the life-cycle health investments take an ex-ante stance, with individuals being able to foresee the development of their health perfectly. However health shocks with significant impacts on the individual life (life-threatening diseases, accidents, chronic diseases) should not be averaged into a mean value, as they potentially put the entire life-course on a different trajectory. We introduce a dynamic optimal control framework incorporating a stochastic health shock with individuals allocating resources to consumption and different kinds of health investments over their life-cycle. We distinguish between general health care and shock specific prevention, acute and chronic care. This setup enables us to analyze how the shock risk shapes the individual behaviour with respect to the different types of health expenditures and how medical shocks change the trajectories of consumption and savings. Newly developed transformation techniques allow us to investigate the optimal decisions made in anticipation of a potential health shock and the optimal reaction to all possible shock scenarios. We are able to obtain analytic expressions for the consumption and health investment profiles before and after the shock and identify the driving forces for the decisions. Furthermore we derive expressions for the values of life, prevention and abatement for all possible shock scenarios and provide some stylized numerical results.

4 - Extension of the rational addiction model: a two-stage approach
Stefan Wrzaczek, Michael Kuhn

We consider the well known rational addiction (RA) model introduced by Becker and Murphy in 1988. We extend the model and assume that addiction evolves over two stages. In the first stage, the addiction does not have negative effects on the individual and the utility of consumption is independent from the stock of addictive consumption. In the second stage, the assumptions are similar to the classical RA-model and its various extensions. The stock has a negative effect on the individual utility and the utility of consumption depends positively on the stock. Furthermore we assume that the income is lower during stage 2, since the productivity suffers from being addictive. The model switches from stage 1 to stage 2 by a stochastic switching rate which strongly depends on the stock of addictive consumption. We intend to observe the optimal consumption strategy under the condition that 'escalation of addiction' strongly depends on the past consumption.

Tuesday, 14:30-16:00

■ TD-01
Tuesday, 14:30-16:00 - O'Reilly Hall

Bernd Bischl

Stream: Tutorials
Tutorial session
Chair: *Cristinca Fulga*

1 - Bayesian Optimization and Automatic Machine Learning
Bernd Bischl

The talk will cover the main components of sequential model-based optimization algorithms a.k.a Bayesian optimization. Algorithms of this kind represent the state-of-the-art for expensive black-box optimization problems and sequential planning of experiments, and are getting increasingly popular for hyper-parameter optimization and automatic machine learning (AutoML). After covering the fundamentals, I will outline some extensions w.r.t. to parallel point acquisition, and multi-objective optimization. The talk will conclude with the discussion of some open challenges.

■ TD-02
Tuesday, 14:30-16:00 - Moore Auditorium

Women in OR - Workshop

Stream: Women in OR
Tutorial session
Chair: *Paula Carroll*

1 - Women in OR - workshop
Paula Carroll

Following on from the Women in OR main session on Monday, this session allows participants to discuss issues raised and ways forward. To maintain momentum on a EURO level, what networking and evaluation systems might we put in place to successfully address issues of equality and diversity in the field of OR?

■ TD-03
Tuesday, 14:30-16:00 - Q106

Roundtable 2: Successful factors of industry/academics partnerships

Stream: Practice of OR (Making an Impact)
Tutorial session
Chair: *Michele Quattrone*

1 - Roundtable 2: Successful factors of industry/academics partnerships
Michele Quattrone

Around this roundtable, the panel will discuss about the key ingredients that make an industry/academic partnership successful from an industrial and academic points of view. How do we initiate such partnerships? How do we track the evolution? Do we need to precisely define the roles in such partnerships ? What is expected from industrials by academics: data, real life topics, business expertises...? What is expected from academics by industrials: scientific excellence, modeling practice, algorithmic developments, hype technological check...? What are the final output of such collaboration expected: prototyped models, feasibility studies, Proof of concepts...? What are the issues that are regularly faced in such collaborations: misunderstandings, Intellectual Property,...?

■ TD-04

Tuesday, 14:30-16:00 - Q116

Teaching OR/MS 4

Stream: OR Education
Invited session
Chair: *Volker Kraft*

1 - Improving teaching Operations Research through game-based learning
Marina Segura, Concepción Maroto, Concepción Ginestar, José Ramónn Navarro

Literature shows that gamification is a recent strategy in academic courses that allows increasing students' engagement. We have implemented an innovative education project which integrates game-based learning in classroom and laboratory classes with the objective to improve students' motivation and learning outcomes in an Operations Research course in Business Administration and Management. For this experience we have used the platform Kahoot!, which is free for teachers and permits students to answer questions on their own smartphones and an immediate feedback for both teachers and students. We have analysed the opinions of the students involved, for example if they think this experience is fun, if it is useful to review concepts or if it is a challenge to encourage them to study more regularly. The influence of the designed games on the motivation and the competitiveness among of students are studied, as well as if these digital games are appropriate tools for continued assessment in classroom and lab. As the students have different goals and learning styles, we have also discussed the relations between their perceptions with respect to Kahoot! games and other educational resources (books, slides, screencasts…) used in order to facilitate and reinforce Operations Research learning. Finally, digital games represent an opportunity to extend learning resources and experiences with a positive impact in the performance of some students.

2 - Convincing MBA Students on the Need for Regression
Lori Murray, John Wilson

Many MBA students dislike multiple regression and want to only compare two variables two at a time and calculate univariate summary statistics. We provide a method that, for any given set of univariate statistics, generates two underlying multivariate data sets that give opposing results demonstrating the need to use multiple regression.

3 - Standards and the Role of Technology in OR Education
Volker Kraft

This talk discusses the emerging importance of standards for education in OR. The US Common Core Standards and GAISE recommendations provide guidelines on analytics education at the K-12 and post-secondary level. A common thread is the effective use of technology.

The technology of choice must be easy to use, visual, interactive and dynamic. In addition, it must allow students to explore abstract concepts and what-if scenarios through interactive simulations, and allow application of statistical concepts to real world problems and scenarios. An example of this would be a visual and interactive method of teaching resampling methods, a topic that is often thought to be abstract and challenging to teach in introductory classes.

Several examples will be explored and best practices will be discussed, using JMP statistical discovery software from SAS.

■ TD-05

Tuesday, 14:30-16:00 - A003

Spatial Multiple Criteria Analysis of Urban and Environmental Qualities

Stream: Decision Analysis
Invited session
Chair: *Giovanna Fancello*
Chair: *Alexis Tsoukias*

1 - Contribution to subjective welfare measurement.
Giovanna Fancello, Alexis Tsoukias

Measuring welfare is a crucial aspect for any policy design activity. We propose a framework for measuring welfare which takes into account both the multidimensional nature of welfare as well as the subjective aspects related to "welfare perception" and individual abilities. For this purpose we use Capability Theory and we explore how this can turn to an operational tool. We use examples from poverty measurement and urban quality measurement.

2 - The Value of Urban Quality: a proposal for a hybrid approach
Alessandra Oppio, Marta DellOvo, Federico Dell'Anna, Marta Bottero, Laura Gabrielli

The quality of the built environment is a multidimensional notion, as it deals with the land use patterns and mixes, the spatial and temporal distribution of activities, the accessibility to services, the open spaces and green areas, the air quality, the arrangement and appearance of the physical elements of urban design. Although several studies have listed the environmental, social and economic benefits of good urban design for many stakeholders, there is a small body of literature on their monetary value. Most of the scholars focus on the impact of open spaces, urban parks, and amenities on residential property values, without providing a real monetary estimation of the quality of public goods and services. The present paper focuses on the contribution of urban quality on real estate value. Given the spatial nature of the problem and the multifaceted aspects to be considered, a hybrid evaluation approach has been defined by combining Spatial Multicriteria Analysis with Hedonic Price Method. In order to explore the impact of urban quality improvements on real estate value, the proposed evaluation approach has been applied to three urban districts in the city of Milan (Italy), with different location features.

3 - Evaluate adaptation options considering vulnerability and decision-makers preferences: a decision support approach
Giulia Lucertini, Denis Maragno

Adaptation to climate change is certainly a task that affects all levels of government and a great variety of actors worldwide. However, climate change effects and impacts are very often place-specific and local authorities are in the front line of the adaptation problems. At the same time, local authorities are often unprepared to deal with such challenges, which can depend on poor understanding of the problem (also resulting from lack of quality information) and on the lack of suitable tools to take proper decisions. To overcame this situation we propose a spatial decision support approach based on local climate vulnerability and a set of common and shared indicators to assess partners adaptation options. The approach, that is created and tested both in Italian and Croatian territories, is build in order to support local administration during the Adaptation plan development. This approach is the main output of iDEAL project (INTERREG IT/HR), that involved five administration into the Adriatic territory. It helps in evaluation and visualization of the results of different adaptation option involving the relative stakeholders and decision-makers from the early stage of planning.

4 - The value of a Rolling tree in a flexible context: an agriculture case
Elbio Avanzini, Alejandro Mac Cawley, Jorge Vera, LluisM Pla, Sergio Maturana

Flexibility has been recognized as a mechanism for handling uncertainty. However, evaluating its value when different sources are present, it's a difficult task. Literature indicates that operational and resources flexibility is often used. The manager also considers the features of the decisions processes, so the value of the system is a combination of both sources of flexibility. In our belief, the balance among resources and decisions flexibilities has not been studied in depth. In this work, we will use the grapevine harvesting case to study the value and sources of flexibility. Rain occurrence generates uncertainty in the maturation process and deteriorates the quality of the product and its market price. The goal of the manager is to maximize the profit of the harvesting and to do so he/she decides about labor quantity and blocks allocation. However, rainfall also decreases the productivity of labor. We propose a decision process consisting of an algorithm based on multi-stage stochastic programming for short term decisions and an expected value model for the rest of the harvest window. We aim to value the contribution of the decision process itself when specific labor flexibility is present and to understand the effects of the structure of the rolling tree in this value.

■ TD-06

Tuesday, 14:30-16:00 - A004

Modelling approaches for policy planning and evaluation

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Eglantine Künle

1 - Grid-scale life cycle greenhouse gas implications of electricity storage and carbon pricing options
Sarah Jordaan, Qingyu Xu, Ben Hobbs

Models that characterize life cycle greenhouse gases from electricity generation are limited in their capability to estimate emissions changes at scales that capture the grid-scale benefits of technologies and policies that enhance renewable systems integration. When quantifying the life cycle emissions of an electricity grid, national assumptions about the generation mixes are often applied at annual time steps, neglecting to account for the regionalized differences in power systems that can result in variable emissions results. We develop a grid-scale life cycle model that incorporates details of transmission and generation planning, which allows a geographically textured and thus more realistic assessment of life cycle greenhouse gas impact of storage and policy options. Results from a co-optimized model of generation, transmission and operations, entitled the Johns Hopkins Stochastic Multistage Integrated Network Expansion Model (JHSMINE), will provide a detailed characterization of storage scenarios. The analysis will focus on the western interconnection comprising the western geographic area of North America where the grid is synchronously operated. Scenarios will include effects of carbon prices, the addition of 1200 MW of Pumped Hydro and the addition of 1200 MW of Compressed Air Energy Storage with new wind capacity. Our approach will capture life cycle emissions associated with different planning outcomes, from fuel extraction through electricity generation.

2 - A new approach for measuring the data aggregation quality in power systems optimization.
Lucas Condeixa, Fabricio Oliveira, Afzal Siddiqui

Due to more stringent clean-energy policies and, consequently, deeper renewable-energy penetration, optimizing decisions in energy systems planning involves handling uncertainty effectively. This allied with large datasets poses the challenging task of efficiently modelling system stochasticity. Alternatives to reduce the computational burden are load levels, representative days, between other data aggregation methods. Clustering techniques have been used to model power systems as they can present consistent and simple solutions as inputs for the infrastructure expansion decisions. Nevertheless, with several alternative clustering techniques available, it can be difficult for the decision maker to elect one. This work presents a framework for comparing clustering techniques in the context of power systems optimization and support the definition of suitable sets of scenarios to be used in a stochastic programming model. We propose a Wasserstein distance-based metric to evaluate the representation quality of different data aggregation. The aforementioned data aggregation techniques were applied to real two-dimensional data based on demand and renewable energy generation (i.e., wind power) to illustrate the suitability of the metric presented. Consequently, we provide an assessment of the performance of different clustering techniques in terms of their correspondence to the original data (i.e., quality), the number of clusters (i.e., resolution), and computational requirements.

3 - The Gap Between Energy Policy Challenges and Model Capabilities
Lukas Schmidt, Christoph Weissbart, Kais Siala, Karen Pittel

The transition of power supply to systems with a low emission-intensity imposes a great challenge to policy makers. To tackle the problem and due to computational developments, numerous energy system models with rising complexity were devel-oped. Moreover, the lack of transparency makes the assessment of model suitability for policy questions challenging. Consequently, from the perspective of policy makers and the scientific community itself, there is little knowledge to what extent relevant and robust insights for policy makers can be provided. Therefore, this contribution systematically assesses the ability of energy system models to answer major energy policy questions. First, we propose a set of criteria to compare a sample of 40 models. Second, a model-oriented approach is developed to characterize energy policy questions. Finally, the model capabilities and the policy questions are brought together by quantifying the suitability of models to address policy questions. We find that some models are very well able to answer a wide range of energy policy questions, whereas others specialize on a specific field. The representation of the distribution grid, the endogenous adjustment of demand, and the technical flexibility of the energy system are among the features, where models deliver little insight. Our results provide policy-makers with guidance on crucial model features with respect to a selection of energy policy questions and suggest potential research directions.

4 - Myopia and uncertainty in energy system planning
Fabian Arnold, Samir Jeddi, Eglantine Künle, Lukas Schmidt

We address the research question of interim targets timing to reach the long-term greenhouse gas abatement obligations when accounting for inertia and uncertainty. Therefore we introduce myopia and stochasticity in a technology-rich partial equilibrium energy system optimization model. This work is limited to modelling approaches in energy system models that can be used both in perfect foresight and myopic mode, and their use in tandem to win policy insights for system decarbonization. Myopia is used to represent sequential decision making and the short-sightedness of actors taking investment decisions. Stochasticity is used as a way to include uncertain developments in the building sector. In this setup, combined myopia and stochasticity allow accounting for realization of (uncertain) changes in conditions and external shocks.

In a first step, we analyze the impact of timing of emission targets on the total system costs in a myopic environment compared to a perfect foresight environment. In a second step, we analyze how robust the greenhouse gas reduction path policies are toward stochasticity. We thereby address the uncertainty around disruptive events in the building sector. The geographic scope is Europe with focus on Germany. All assumptions and input data are based on the technology-open scenario of the dena Study "Integrated Energy Transition".

■ TD-07

Tuesday, 14:30-16:00 - A007

OR in Forestry III

Stream: OR in Agriculture and Forestry
Invited session
Chair: *Alexandra Marques*
Chair: *Ricardo Soares*

1 - Multiple vehicle synchronisation in a full truck-load pickup and delivery problem: a case-study in the biomass supply chain

Ricardo Soares, Alexandra Marques, Pedro Amorim, Jussi Rasinmäki

In this work, the full truck-load pickup and delivery problem with multiple vehicle synchronisation (FT-PDP-mVS) is presented. It consists in determining integrated routes planning for three distinct types of vehicles which need to perform interrelated operations with minimum logistics costs. This problem has application in the biomass supply chain, as different vehicles involved in wood chipping and transportation need to be synchronised when these operations are combined at the roadside of forest sites. We extend existing studies in synchronisation in vehicle routing problems by acknowledging multiple synchronisation aspects, and present a novel mixed integer programming model (MIP) and transportation network to successfully model the problem. Furthermore, a solution method is developed for solving large-scale instances, based on the fix-and-optimise principles under a variable neighbourhood decomposition search. Its performance is tested through a set of computational experiments, based in a case-study from a biomass supplier in Finland, where significant gains in overall logistics costs can be acknowledged. Furthermore, additional computational experiments provided valuable insights about the impact of key parameters of biomass logistics over the routing results.

2 - An Approach to enrich the Optimization of the Forest-based Supply Chain by Semantics

Johannes Scholz, Alexandra Marques

Contemporary digital methods and techniques for optimizing the FbSC are getting growing attention, as the raw material wood is a climate-neutral good. In order to better utilize the resource forest and the subsequent Forest-based supply chain (FbSC) the digitization of the processes seems inevitable. In addition, digitization could enhance the horizontal and vertical cooperation between stakeholders in the FbSC. Nevertheless, institutional borders as well as IT-related limitations - especially syntactic (to a lesser degree) and semantic interoperability - hinder cooperation. For the FbSC semantics could help to share data between stakeholders and IT-systems as well, in a way that the meaning of data are clearly defined. In particular a Linked Data representation enables (geo-) semantic queries on multiple datasets. Hence, Decision Support Systems and optimization systems could "crawl" the Linked Data Cloud for appropriate data for a specific purpose. The results of any Decision Support System, and optimization, could be made available to the stakeholders and their IT systems in a semantically enriched manner. This would pave the way to overcome interoperability issues, which are the result of different systems and/or data formats involved in the FbSC. This could be realized by describing data/formats with the help of a shared ontology, defining "what is" in a system independent way - e.g. as Ontology Web Language.

3 - Achieving optimal close-to-nature management through the digital representation of forest ecosystems

Gaspard Dumollard, Christian Rosset

Close-to-nature forest management is a particularly demanding process due to the great complexity of forest ecosystems, the slow unfolding of intervention effects on tree development, the necessity of reconciling several forest functions, and the presence of disturbances and uncertainties.

The increasing number and variety of available sensors (e.g. remote sensing, embedded in smartphones, in situ connected sensors) allows a tight forest monitoring and an always improving understanding of forest ecosystems dynamics, which is crucial for an effective and efficient close-to-nature silviculture. An inventory system making a practical use of such sensors is currently deployed in a case study in Switzerland.

This presentation proposes a vision to leverage all available data to build an integrated and (real) time digital representation of forest ecosystems in the perspective of the Industry 4.0. The main challenge is to build a representation holding enough differentiated and context-specific information to be relevant to close-to-nature forestry. Augmented with digital tools for modeling forest growth and the impact of silvicultural interventions, and with a system of objectives corresponding to multifunctional forests, this representation would consist of a tool for the optimal and adaptive steering of forest ecosystems.

4 - Using optimization-simulation techniques for planning and control biomass logistics operations

Reinaldo Gomes, Alexandra Marques

Optimization methods proved to be valuable for developing optimal plans for biomass logistics that balance the woodchips demand and supply, seeking for higher process efficiency and cost savings. However, operations may not be executed as planned due to unforeseen events such as delays or changes at the demand and at the supply sides. Digital technologies can be valuable to monitor operations execution ad detect, in real time, situations that may affect the plans. In this paper we propose a discrete-event simulation approach that is feed by real-time execution updates and controls the execution of the logistics plans. In fact, the proposed approach anticipates the level in each the plan will be executed. Whenever the deviations are significant, a new replanting can occur. This paper also discusses the replanning loop, also called the feedback loop from simulation to optimization. The proposed approach was tested in a case study in a biomass logistics company in Portugal.

■ TD-08

Tuesday, 14:30-16:00 - A008

Optimization under Uncertainty: theory and applications

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Francesca Maggioni*
Chair: *Ehsan Izadpanahi*

1 - Stochastic multi-path Traveling Salesman Problem with dependent random travel costs: a new deterministic approximation

Daniele Manerba, Edoardo Fadda, Lohic Fotio Tiotsop, Roberto Tadei

The stochastic multi-path Traveling Salesman Problem aims at finding the expected minimum-cost Hamiltonian tour in a network characterized by the presence of different paths between each pair of nodes, given that a random travel cost is associated with each one of these paths. Differently from most of the existing literature, we relax the assumption of independence among the path travel costs, which is far to be reasonable in realistic settings affected by traffic congestions, accidents, and other unexpected events. More precisely, we assume the path travel costs to be identically distributed but just asymptotically independent. First, through the extreme value theory, we derive a new deterministic approximation of the problem. Computational tests on extensive sets of random and realistic instances show very good efficiency and accuracy of our approach with respect to Stochastic Programming models with recourse, totally overcoming the computational burden of solving enormous programs exploded by the scenarios considered. Second, we can also relax the previous requirement on the distribution tail to a more general assumption, which is satisfied by many more distributions. Finally, we show that the asymptotical independence is not restrictive at all when considering realistic traffic models and the well-known Wardrop's equilibrium principle, ensuring strong operational implications to our deterministic approximation.

2 - Two-stage Stochastic Optimization of Standard Quadratic Problem for Clustering in Social Networks
Markus Gabl, Immanuel Bomze, Francesca Maggioni, Georg Pflug

We present a stochastic optimization model for the widely applicable Standard Quadratic Problem (StQP), the simplest class of deterministic NP-hard optimization problems which consists of optimizing a quadratic form over the standard simplex. While both the robust counterparts and the average case within this class seem to be well understood to some extent, apparently a two-stage stochastic optimization approach to problems of this type has not been analyzed before. We assume that parts of the problem data of the StQP are uncertain but to know their probability distributions. Our aim is to find a cluster among elements corresponding to the certain parts of the matrix in the first stage such that it can be completed to a dominant set of the entire instance once the uncertainty is revealed in the second stage. To achieve this, we tackle an auxiliary problem, which corresponds to a two-stage stochastic version of the StQP. For this problem we study bounds derived from stochastic optimization theory as well as algorithms for finding good feasible solutions. Further, we investigate how well the auxiliary model performs in delivering the desired adaptable first stage decision for the actual problem. We also present possible applications, such as selecting invited speakers for conferences. in a way to maximize impact in the sense of generating a community with high coherence, i.e. an influential cluster.

3 - Integrated tactical and strategic planning for energy transition in manufacturing firms: A robust optimization approach
Ehsan Izadpanahi, Tiru Arthanari

Energy transition in manufacturers is inevitable due to global energy consumption pattern changes. For developing an efficient energy transition plan, manufacturers need to integrate transition decisions to operational planning. Capacity expansion planning (CEP) models may be an appropriate framework in which energy related decisions can be integrated to operational decisions. To pursue this, we develop a mixed integer linear programming (MILP) model which considers capacity planning, energy transition decisions, energy planning and the production level for satisfying customers' demands in each period. In order to handle the inherent uncertainty in the proposed model, a robust optimization approach will be developed. This approach is especially appropriate when the distribution function of the uncertain parameters is not known. Finally, the proposed approach will be implemented in a real case study. Thanks to the critical role of energy in energy intensive process industries (EPIs), the case study is a smelting factory. We study the effect of energy decisions on operational decisions and analysis the sensitivity of different parameters in the model.

■ TD-09

Tuesday, 14:30-16:00 - B006

Performance Measurement II

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Maria Silva

1 - The Effciency Implications of Political Donations
Vitezslav Titl, Kristof De Witte, Benny Geys

Firms' political donations can induce distortions in the allocation of public procurement contracts. In this article, we employ an advanced non-parametric efficiency model to study the public sector (cost) efficiency implications of such distortions. Using a unique dataset covering the Czech regions over the 2007-2014 period, we find that the efficiency of public good provision is lower when a larger share of public procurement contracts is awarded to firms donating to the party in power ('party donors'). We then link this efficiency difference to two underlying mechanisms: i.e. shifts in procurement contract allocations from firms with previous procurement experience to party donors, and the use of less restrictive allocation procedures that tend to benet party donors.

2 - Efficiency Analysis in the Presence of Demand Uncertainty
Chris O'Donnell, Tarmo Puolokainen

We consider a service industry in which a principal supplies inputs to agents in different jurisdictions in the face of uncertainty about the services that will be demanded in each jurisdiction. The principal aims to minimize the cost of the inputs supplied. Each agent aims to use his/her allocated inputs to provide the services demanded in his/her jurisdiction. Under-resourcing of agents can lead to unacceptable levels of service. This can reflect badly on both the principal and the agents. We show how data envelopment analysis (DEA) can be used to estimate the cost efficiency of the principal, any under-resourcing of the agents, and the technical and mix efficiency of the agents. In an empirical illustration, we find evidence that 10-25% of rescue service brigades in Estonia are under-resourced. We also find that minimum service levels could have been met in all jurisdictions for 30% (approx. 10 million euros) less than it cost in 2015.

3 - DEA with multi-valued measures
Mehdi Toloo, Jana Hanclova

In the classical DEA models, it is assumed that each data (input or output) has a single value. However, in some real-world situations, there are some data with more than one value which are measured by various standards. For instance, the unemployment rate is a multi-valued measure in economic applications since several definitions or standards exist to measure it. This study develops an approach for selecting a suitable value for a multi-valued measure. We suggest two individual and summative selecting directional distance models. A case study of 183 NUTS 2 regions in 23 selected EU-28 countries is taken as an example to validate our approach.

4 - Analysing the export potentials of the Portuguese footwear industry by Data Envelopment Analysis: When the inefficient are the focus
Maria Silva, Dimitrios Sotiros, Vasco Rodrigues

The shift and involvement of national economies into a global economic system have led to a considerable growth of trade among the countries in a world-wide level. The exponential increase of the world exports' value, during the last seventy years, has also transformed the national economies and international trade is considered a key factor for the countries' economic growth. In this line of thought, an increasing literature body is focused on the development of parametric approaches to analyse and identify trade potentials across different countries. The majority of these approaches rely on the gravity model, which is the main instrument for empirical studies in international trade whereas non-parametric techniques have been scarcely employed in the literature. In the current paper, we analyse the Portuguese footwear industry's export potentials by employing Data Envelopment Analysis (DEA) - a non-parametric technique of efficiency frontier analysis. We develop a DEA framework to identify the countries that in the last years showed a good export performance for Portugal, to understand the factors that determine Portugal's best export performance for certain countries, to identify countries where export performance has been poor in the last years and among these countries to find those with the greatest export potential. We use panel data from 2011 to 2017 and our analysis provides a meaningful interpretation of the results as well as valuable insights.

■ TD-10

Tuesday, 14:30-16:00 - H0.12

Surrogate Optimization: Methods and Applications

Stream: Derivative-free Optimization
Invited session
Chair: Delphine Sinoquet

1 - Bayesian optimization in effective dimensions via kernel-based sensitivity indices
Adrien Spagnol, Rodolphe Le Riche, Sébastien Da Veiga

A determining factor to the utility of optimization algorithms is their cost. A strategy to contain this cost is to reduce the dimension of the search space by detecting the most important variables and optimizing over them only. Recently, sensitivity measures that rely on the Hilbert Schmidt Independence criterion (HSIC) adapted to optimization variables have been proposed. In this work, the HSIC sensitivities are used within a new Bayesian global optimization algorithm in order to reduce the dimension of the problem. At each iteration, the activation of optimization variables is challenged in a deterministic or probabilistic manner. Several strategies for filling in the variables that are dropped out are proposed. Numerical tests are carried out at low number of function evaluations that confirm the computational gains brought by the HSIC variable selection and point to the complementarity of the variable selection and fill-in strategies.

2 - Calibration of noisy black-box functions
Benjamin Marteau, Lindon Roberts, Coralia Cartis

From many fields of applications, calibrating numerical models is an important goal of optimization. Very often, evaluating these models involve heavy computations that can be either very expensive or noisy if they are not run to full convergence. In such a case, using classical derivative-based optimization methods may not be advised as computing the model's gradient can become a difficult challenge: finite-differences are often not realistic in terms of computing time and even more sophisticated methods such as algorithmic differentiation can fail in the presence of noise.

We present in this talk a state-of-the-art implementation of a model-based derivative-free algorithm for nonlinear least-squares problems. It is specifically designed to handle expensive and noisy objective functions thanks to some important features. First, inspired by the Gauss-Newton method, it builds simple linear regression models for each of the residuals, allowing for a cheap and precise quadratic regression model of the objective. It also has a flexible initialization phase for very expensive functions and can start optimizing with as few as two objective evaluations. Finally, robustness with respect to noise is achieved thanks to the automatic detection of progress stagnation.

We will also show extensive numerical experimentation as well as a financial industry application to illustrate the performances of the solver.

3 - Mixed global optimization by algorithms composition: an empirical study with a focus on Bayesian approaches
Rodolphe Le Riche, Marie-Liesse Cauwet, Olivier Roustant

Nonlinear optimization problems involving both continuous and discrete variables remain a theoretical challenge with important practical implications. Recently, Bayesian optimization algorithms have been extended to mixed variables problems and offer a mathematical model to handle mixed variables. Bayesian algorithms contain an internal optimization problem, typically the maximization of the expected improvement. Although a large number of evaluations is possible for this internal problem, it still contains mixed variables. In this work, we propose to address such problems by composing state-of-the-art continuous and discrete global optimization algorithms. These algorithms are tested on a series of analytical and expected improvement functions. It turns out that the best algorithms for composition are the noisy variants, i.e., the algorithms that take into account the possibility of an inaccurate evaluation of the search points.

4 - Derivative Free Optimization with mixed discrete and continuous variables : motivations and limitations of the current methods
Miguel Munoz Zuniga, Delphine Sinoquet

Many applications of black-box optimization with mixed discrete and continuous variables derive from optimal design problems. The variables involved in those problems can be integer variables as a varying number of components of the system, categorical variables (usually non ordered) associated with different material types, binary variables indicating the presence or not of certain components and continuous variables describing the dimensions or characteristics of the structure. The objective functions and constraints are mostly outputs of an expensive-to-evaluate simulator. In this talk we will motivate the development of appropriate optimization methods by presenting several applications: optimization of the offshore wind turbine mooring system, optimization of the blades of turbo-machinery for aircraft, oil field development and optimization of machine learning hyper-parameters. Two types of methods extended to mixed continuous and discrete variables will be discussed: optimization based on surrogate models of the objective functions and derivative free trust region method. The current limitations of these two families of methods will be discussed.

■ TD-11

Tuesday, 14:30-16:00 - H1.12

MINLP with Differential Equations

Stream: Mixed-Integer Nonlinear Programming
Invited session
Chair: Falk Hante

1 - Direct Methods for Mixed-Integer ODE-Constrained Optimization
Falk Hante, Martin Schmidt

We consider mixed-integer nonlinear optimization problems with constraints depending on initial and terminal conditions of an ordinary differential equation. A direct method is to replace the dynamics with a discrete approximation and to solve the corresponding finite-dimensional mixed-integer nonlinear optimization problem. The talk discusses the convergence of this solution approach when the approximation is refined. We provide critical examples and a set of conditions ensuring convergence in the sense of the corresponding optimal values. The results are obtained by considering the discretized problem as a parametric mixed-integer nonlinear optimization problems in finite dimensions. The necessity of the conditions is discussed on the example of pipe sizing problems for gas networks.

2 - An outer convexification approach to control transportation networks
Simone Göttlich

Outer convexification is a suitable tool to solve optimal control problems constrained by differential equations, where the controls are either integer or binary valued. For the applications under consideration, as for instance traffic flow, electrical grids or production systems, the dynamics is governed by conservation laws. Typical controls are then traffic lights or routing decisions in networks. We will introduce a solution heuristic consisting of the solution of a nonlinear problem with dynamic constraints and a reconstruction mixed-integer linear program without dynamic constraints. The approach is based on a discrete approximation lemma for outer convexification, whose grid-independence properties for conservation laws are investigated. Numerical results show the good performance of this solution approach.

3 - Global optimization of ODE constrained network problems
Oliver Habeck, Marc Pfetsch, Stefan Ulbrich

We present an approach for global optimization of mixed-integer nonlinear optimization problems with ordinary differential equation constraints on networks. Throughout the talk, we will use stationary gas transport as a running example. In stationary gas transport it is easy to see that gas cannot flow in cycles unless pressure is increased by compressors. Based on this observation, we are going to consider combinatorial models for flow directions of potential-based flows.

Our approach for handling the ODEs is based on spatial branch-and-bound. In order to use that, we construct relaxations of the ODE solution operator, i.e., the mapping from initial values to end values. These relaxations are based on numerical discretization schemes, which provably yield lower and upper bounds on the end values. We discuss under which condtions the discretization schemes already produce convex under- and concave overestimators for the ODE solution operator and show that we can use them without adding additional variables to our model.

4 - Towards Sequential Action Control for Gas Network Control.
Yan Brodskyi, Falk Hante

In this talk we discuss two extensions of the framework of sequential action control (SAC) principle. The main idea of SAC is to use the so called moving horizon strategy. Instead of finding in each step of a receding horizon the full time dependent optimal control solution of the optimization problem, SAC finds a constant optimal control value and time to act that maximally improves the performance. Our two extensions concern firstly systems of partial differential equations which can be posed as abstract linear control problems in a Hilbert space and secondly integer constraints for the distributed control. Both extensions are motivated by the properties of gas network problems. We present theoretical results and a numerical study.

■ TD-12

Tuesday, 14:30-16:00 - H1.51

Knapsack and assignment problems in scheduling, logistics and healthcare

Stream: Combinatorial Optimization I
Invited session
Chair: *Mikhail Y. Kovalyov*
Chair: *Erwin Pesch*
Chair: *Alain Quilliot*

1 - Machine scheduling with non-renewable resources
Tamas Kis, Péter Györgyi

Machine scheduling problems can naturally be extended by additional non-renewable resource constraints, such as raw materials, energy, or money. In these models, beside the machine(s) and the jobs, there is an initial inventory from the various resource types, and some additional supplies at given dates and in known quantities. The jobs require some quantities from each resource type, and a job can only be started if its requirements are on stock. When a job is started, the available quantity from each resource type is reduced by its resource requirements. The objective function can be e.g., the makespan, or the total weighted completion time, or any standard objective function. Non-renewable resource constraints can be modelled by nested knapsack constraints, where the item sizes are given by the resource requirements of the jobs, and the knapsack capacities are the total supplies up to the supply dates. In the proposed talk we overview some old and new complexity and approximability results in this area. We will consider the most basic objective functions, and single and parallel machine environments as well. We will present some details of our recent results on the complexity and approximability of single machine problems with the total weighted completion time objective. We will finish the talk by some open problems of the area.

2 - Algorithm Portfolios for Large Berth Allocation Problems
Maciej Drozdowski, Jakub Wawrzyniak, Eric Sanlaville

In this presentation algorithm selection for berth allocation problem (BAP) under solution time limits is considered. BAP consists in scheduling ships on berths subject to ready times, ship size constraints, for minimum turnaround time. In strategic port capacity planning BAP is solved many times in simulations. An approach is proposed to select a portfolio of algorithms solving a BAP instance and returning the best solution. The algorithm portfolio must obey runtime limit while minimizing overall solution quality loss. The portfolio evolves with changing runtime limit which is a key design decision in the simulations. The portfolio is constructed on the basis of training instances performance measured by the runtime and solution quality. Evolution of the algorithm portfolios under changing runtime limits is studied.

3 - Scheduling of maintenance of locomotives in the depot
Egor Grishin, Alexander Lazarev, Elena Musatova, Ilia Tarasov, Semen Galakhov, German Tarasov

We consider a real-world problem of planning operation of locomotive maintenance depots (LMD) in operation of the Russian Railways. We are provided a 24 hours plan of locomotives arriving to the LMD. The locomotives differ in series, number of sections and maintenance duration. LMD consists of up to one buffer track and a set off access tracks, each of them ending with its own single maintenance track. Upon arrival each locomotive can be placed into the buffer for some period of time and then moved to one of the access tracks, or it can be placed directly on an access track. Each of the tracks has a limited capacity measured in locomotive sections. Each maintenance track can only service a certain set of locomotive series. The buffer track operates like a stack. The goal is to decide for each locomotive, whether it should be placed into the buffer, which access and service tracks it should be placed on, and the time intervals of its presence on each of these tracks. We consider four different objective functions to minimize: the total idle time, maximum idle time, total waiting time and makespan. We propose a dynamic programming algorithm, a constraint programming model for IBM ILOG CPLEX and a heuristic algorithm. The algorithms and the model were tested on real data for LMD configurations of the Eastern area of Russian Railways. The resulting schedules were then compared with the ones implemented by the Russian Railways. This work has been supported by RFBR 18-07-00656.

■ TD-13

Tuesday, 14:30-16:00 - H2.12

Stability analysis and optimality conditions of variational systems

Stream: Nonlinear Programming. Theory and Methods
Invited session
Chair: *Hector Ramirez*

1 - Stability analysis for parameterized conic programs
Hector Ramirez

In this talk we first visit several results characterizing well-known stability properties (such as Aubin property, isolated calmness, etc.) for critical maps of parameterized conic programs. These characterizations are typically carried out via the computation of second order generalized derivatives, and we need the constraint set is defined over a convex cone satisfying a reducibility assumption and is (strongly) qualified. Then, we present an ongoing work, which aim is to prove/extend those results under weaker qualification constraints conditions, establishing some connections between second order derivatives and well-known conic tools, such as the sigma term. Our approach covers seminal examples such as (nonlinear) SDP and SOCP.

2 - Optimality conditions in semi-infinite programming free of qualification conditions
Rafael Correa, Abderrahim Hantoute, Marco A. López-Cerdá

We derive new Fritz-John and KKT-type optimality conditions for semi-infinite convex optimization problems, dropping out the usual continuity/closedness assumptions (see, for example, [1]. When the family of functions is Ofinite, we use continuity conditions concerning only the active functions.

[1] Dinh, N, Goberna, M.A., López, M.A., Son, T.Q., New Farkas-type constraint qualifications in convex infinite programming. ESAIM: COCV 13 (2007), 580-597.

3 - Equilibrium, Nonlinear Hahn-Banach and Optimization
Manuel Ruiz Galan

The existence of equilibrium, whose systematic study goes back to the Ky Fan minimax inequality, comprises a wide variety of problems related to optimization, fixed points and variational inequalities, to name a few. We adopt an equilibrium approach to analyze the Hahn—Banach theorem, in order to derive a nonlinear version of this central result of Functional Analysis and Optimization, which allows us to generalize linear results as the Mazur—Orlicz theorem to a nonlinear framework. In addition, both, a nonlinear theorem of the alternative and a result of the Karush—Kuhn—Tucker-type for a class of not very restrictive nonlinear infinite programs, follow from such a nonlinear Hahn—Banach theorem.

■ TD-14

Tuesday, 14:30-16:00 - H2.20

Solution Techniques in Integer Programming

Stream: Mixed Integer Programming
Invited session
Chair: *Arie Koster*

1 - A review of Binary Integer Programming applications and solution methods
Håkon Bentsen, Lars Magnus Hvattum, Sebastián Urrutia

Binary integer programming (BIP) covers a large variety of different problems, with many real world applications. This work first reviews the scientific literature with the aim of creating an overview of the most important applications of pure BIP models. The literature review is conducted using different search strings in order to find the relevant papers from prominent online databases. The findings are then filtered manually and categorized by application. There are relatively few general purpose solvers for BIP, and computational experiments are conducted to show their performance on benchmark instances from the literature, covering a wide variety of applications. Based on these results, we argue that there is a need for improved general purpose solvers for BIP problems, with a performance level closer to what is found in specialized solvers.

2 - The PIP Solver
Issmail El Hallaoui

We introduce the pip (primal integer programming) solver, which at each iteration, improves the current integer solution by finding an improving direction until a near optimal integer solution if found. The solver integrates primal exact and heuristic methods in a highly fluid and conciliate manner. We formalize actually the notion of neighborhood the primal heuristics generally use and generalize some of these latter. Fruitful applications on some transportation problems will be presented.

3 - An integer optimality condition for column generation on binary linear programs
Elina Rönnberg, Torbjörn Larsson

The application of the column generation technique has been very successful for many problem structures in large-scale integer programming, such as routing and scheduling. In the case of solving a linear program by column generation, it is well known that a restricted master problem contains an optimal solution if there remains no column with profitable reduced cost to be added to it. This talk addresses the corresponding question posed for binary linear programs and provides a generic sufficient optimality condition for determining when a restricted master problem contains the columns required to find an integer optimal solution.

The presented condition is also on the reduced costs for columns not yet added, and it is derived from an integer feasible solution to the restricted master problem and dual information from its linear programming relaxation. The integer solution is preferably optimal or near optimal. The dual solution does not need to be optimal; it is however natural to use a high-quality one. We review some situations from the literature when this type of condition is useful and elaborate on how it can be further exploited.

4 - Decision Diagrams for Integer Linear and Nonlinear Programming
Willem-Jan van Hoeve, Christian Tjandraatmadja, Danial Davarnia

Decision diagrams have recently been introduced as an effective tool to represent and solve combinatorial optimization problems. In this presentation we discuss how decision diagrams can be embedded in integer linear and nonlinear programming solvers. We show that decision diagrams of polynomial size can be used to generate strong valid inequalities as well as primal and dual bounds. When the decision diagram represents a substructure of the problem, it can be further strengthened by Lagrangian relaxation and constraint propagation. We provide an experimental evaluation on integer linear and nonlinear programming problems, and demonstrate that decision diagrams can reduce the solving time by up to 60% for some problem classes.

■ TD-15

Tuesday, 14:30-16:00 - H2.32

Vector and Set Optimization

Stream: Multiobjective Continuous Optimization
Invited session
Chair: *Christian Günther*

1 - An Approximation Algorithm for Convex Vector Optimization Problems with Norm Minimizing Scalarizations
Firdevs Ulus, Cagin Ararat, Muhammad Umer

We study Benson-type approximation algorithms for convex vector optimization problems. In general, these algorithms solve a Pascoletti-Serafini (PS) scalarization model in each iteration. Note that the PS model has two parameters: a reference point and a direction vector. The structure of a Benson-type algorithm gives a clear way of choosing a reference point in general. However, there are different approaches to choose a direction parameter and the performance of the algorithm highly depends on this choice. We propose a Benson-type algorithm that solves norm-minimizing scalarizations which do not require a direction parameter. We compare the performance of the algorithm with the existing ones and study the convergence of the algorithm.

2 - Existence Theorems and Regularization Methods for Non-coercive Vector Variational and Vector Quasi-Variational Inequalities
Niklas Hebestreit

In 1980, Franco Giannessi introduced the concept of vector variational inequalities as a generalization of scalar variational inequalities. There are many applications of vector variational inequalities, especially in the areas of multiobjective optimization and vector equilibria problems. In this talk, we present a novel existence result for vector variational inequalities with respect to a fixed ordering cone. Since these problems are ill-posed in general, we further propose a regularization technique for non-coercive problems which allows to derive existence statements even when the common coercivity conditions in the literature do not hold. For this purpose, we replace our original problem by a family of well-behaving problems and study their relationships. In order to justify our abstract framework we apply our results to generalized vector variational inequalities and multi-objective optimization problems. We further consider vector quasi-variational inequalities and prove existence of solutions using a regularization approach and a fixed-point theorem for single-valued mappings.

3 - Scalarization Functionals with Uniform Level Sets in Set Optimization
Christiane Tammer, Truong Q. Bao

We use the original form of a nonlinear scalarization functional with uniform level sets to characterize upper and lower set-less minimizers of set-valued maps acting from a nonempty set into a real linear space with respect to the lower (resp. upper) set-less relation introduced by Kuroiwa. Our main results are: An upper set-less minimizer to a set-valued map (with respect to the image space) is an upper set-less minimal solution to a scalarization of the set-valued map (with respect to the space of real numbers) where the hypergraphical multifunction is involved in the scalarization and vice versa, a lower set-less minimizer to a set-valued map (with respect to the image space) is an upper set-less minimal solution to an appropriate scalarization of the set-valued map (in the space of real numbers) where the epigraphical multifunction is involved in the scalarization and vice versa, and a lower set-less minimizer to a set-valued map becomes a (Pareto) minimizer to the same map provided that the map enjoys a domination property.

4 - Fermat's Rules for Set Optimization Problems with Set Relations
Ernest Quintana, Anh Tuan Vu, Christiane Tammer, Gemayqzel Bouza

In this talk, we consider Set Optimization problems with respect to the set approach. Specifically, we deal with the lower less and the upper less relations. We show that the convexity and Lipschitz properties of the set-valued objective map are transferred to suitable scalarizing functionals. We then obtain upper estimates for Clarke's subdifferential of these functionals. As a consequence of the scalarization approach, we derive necessary optimality conditions for weakly minimal solutions of set optimization problems.

■ TD-16

Tuesday, 14:30-16:00 - Theatre A

Optimization Approaches in the Management of Manufacturing Systems

Stream: Combinatorial Optimization II
Invited session
Chair: *Alena Otto*
Chair: *Olga Battaïa*

1 - The benefits of operation and routing flexibility in automotive flexible assembly layouts
Andreas Hottenrott, Martin Grunow, Maximilian Schiffer

Inspired by technological advances in factory digitalization, the automotive industry has started to investigate flexible layout alternatives to the widespread mixed-model assembly line. In such flexible layouts, the stations are neither arranged serially nor linked by a paced transportation system. Instead, automated guided vehicles transport the vehicles. The sequence of tasks is not predetermined, but can differ for each vehicle (operation flexibility). Also, the same task can be performed at multiple stations (routing flexibility). Due to these flexibilities, the work in progress can be reduced. Assembly scheduling, in contrast, becomes more complex because process planning and routing must be optimized simultaneously.

Against this background, we develop an algorithm that simultaneously optimizes process planning, routing and scheduling. This algorithm yields exact solutions for instances of realistic size. To quantify the benefits of operation and routing flexibility, we compare the simultaneous approach to a hierarchical approach in which process planning and/or routing are decided a priori. In addition, we compare flexible layouts to mixed-model assembly lines.

2 - A Sustainable Closed-Loop Supply Chain model
Zoe Krug, Claudia Oliver-Cortadellas, Olga Battaïa, Romain Guillaume

We propose a multi-objective multi-period mixed-integer programming model for designing a Closed-Loop Supply Chain (CLSC) incorporating reverse logistic flows into an already existing supply chain. Three optimization objectives are considered: the first one is the economic profit maximization, the second one is the environmental impact minimization, and the last one is the employment maximization (social impact). Facilities can be located in different regions characterized by an initial level of pollution and unemployment rate. The decisions about facility location have impact on the final level of pollution and unemployment rate. Our goal is to restore the equity overall the considered regions. In order to achieve this goal, we use the Gini index for both environmental and social objectives. The model is tested on case study.

3 - Insourcing vs. Outsourcing under economical, environmental and social considerations
Narjes Kandil, Olga Battaïa, Ramzi Hammami

We consider an outsourcing problem under economical, environmental and social considerations for a profit-maximizing firm having the possibility of producing in-house or outsourcing a part of its production process to a foreign country. The firm faces a carbon tax and demand and cost uncertainties. We develop analytical approaches to study the impact of environmental regulations and customer environmental awareness on the sourcing strategy and the green investment of the firm. At the beginning of the planning horizon, the firm can make an investment to reduce carbon emissions related to its production process. For the vertically integrated model, we assume that the production zone is so close to distribution that transportation costs and emissions can be neglected. This will lead to a better environmental performance. However, the firm has to take into consideration a carbon tax per unit of emission during the production process. If the firm opts for outsourcing, the objective will be to maximize both the supplier and the manufacturer's profits. The firm will have extra-costs related to transportation and stock. We assume that the manufacturer has to place his orders early in the planning horizon due to a long lead time. With the use of analytical modelling, we derive managerial insights regarding the impact of environmental legislations and customer environmental awareness on the sourcing decisions of the firm.

4 - Integrated Planning and Scheduling of the Steel-Production Processes Continuous Casting and Hot Rolling
Alexander Lohr, Hubert Missbauer

Production planning and scheduling in the steel industry is considered to be one of the most difficult industrial scheduling problems. Two major production steps of the energy-intensive steel production process are continuous casting (CC) and hot rolling (HR), which are often the bottleneck in integrated steel plants and often scheduled separately in practice. During CC, hot steel is cast through a mould as a strand, which is cut in slabs. During HR, hot slabs are rolled flat to steel sheets. Although there is a large number of publications on the separate scheduling of CC and HR, respectively, only very few approaches for integrated scheduling of CC and HR exist. We provide a literature review of existing scheduling approaches and propose a novel model formulation for integrated scheduling of CC and HR, which is developed for a major Austrian steel plant. The formulation considers constraints at these two stages and the upstream steelmaking stage, the demand of steel sheets as well as the capacity of intermediate facilities like heat preservation pits or slab processing. Our scheduling approach is relevant for researchers especially from the decomposition and modelling perspective. An implementation of an integrated CC and HR approach would lead to reduced energy consumption in the production process, increased product quality and lower inventory levels. Furthermore, improved scheduling of CC and HR can decrease the worldwide greenhouse gas emissions considerably.

■ TD-17

Tuesday, 14:30-16:00 - A005

Game theory in energy markets

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: *Carlos Ruiz*

1 - A Robust Approach to Energy Exchanges
Till Heller, Sven Krumke

There have been various approaches for modelling the energy market as an auction, both from the mathematical and engineering point of view. However, the aspect of uncertainty has been mostly neglected. We introduce a new model in which agents submit their bids for selling and buying energy. The goal is to maximize the overall benefit obtained by selecting appropriated bids. One of the main contributions is the incorporation of uncertainty into the model: while the prices can be assumed to be known, in practice the exact amount of energy provided or needed may depend on a number of unknown factors. We prove that even deciding whether a given subset provides a feasible solution for all scenarios in a robust setting with budgeted uncertainty is NP-complete. However, a generalized version of Hoffmann's Circulation Theorem can be used to obtain a practically feasible IP-formulation. We then formulate the overall problem as a robust integer optimization problem and develop an algorithm for solving the problem by a combined row/column generation approach. The algorithm iteratively makes use of feasibility and optimality cuts which are generated by means of subproblems.

2 - On cost-reflectivity of distribution network tariffs: an equilibrium modeling approach
Niels Govaerts, Hélène Le Cadre, Erik Delarue

Recently, traditional volumetric electricity distribution network tariffs have come under scrutiny as the emergence of distributed energy resources (DERs) led to welfare transfers between consumers and cost recovery problems for distribution system operators. Many researchers and regulators argue for more cost-reflective tariffs because they are more efficient in theory, i.e., they lead to an increase of social welfare. One stream of research derives cost-reflective network tariffs from distribution network expansion planning models that allow determining the cost drivers of distribution network operation and investment. In practice, however, network tariffs should adhere to a number of criteria including not only cost-reflectivity, but also cost recovery and simplicity. Perfectly cost-reflective tariffs are typically not simple and do not ensure cost recovery. Another stream of research analyzes the efficiency of simplified network tariffs, explicitly imposing cost recovery. They model a non-cooperative game between consumers attempting to avoid network costs by investing in DERs. In this stream of research, however, simplified network cost functions are typically used, limiting the accuracy of the results. We combine both streams of research by integrating a distribution network expansion planning model in the aforementioned non-cooperative game. The model outcome is used to assess the efficiency of different tariff designs accurately, while ensuring cost recovery.

3 - Investment incentives in electricity markets with regulatory uncertainties and risk averse market participants
Mirjam Ambrosius, Jonas Egerer, Veronika Grimm, Adriaan Hendrik van der Weijde

Striving for more sustainable electricity systems, regulators worldwide have enforced various new regulations and laws in electricity markets. The discussion of potential changes regulation imposes tremendous uncertainty on consumers, producers and system operators alike. We investigate the impact of such uncertainty on risk averse market participants. In particular, incentives for investment in generation and transmission capacity in the long term are quantified by means of a stochastic multilevel equilibrium model including transmission and generation investment, spot market trading and redispatch. Risk aversion of market participants is modeled minimizing market participants' conditional value at risk. We find that risk aversion increases the impact of uncertainty on investment levels and spatial distributions, hindering investment decisions and rendering the system less efficient.

4 - Contract Design in Electricity Markets with High Penetration of Renewables: A Two-Stage Approach
Carlos Ruiz, Rossana Riccardi, Arega Getaneh Abate

In this work, we develop an equilibrium model that characterizes the interactions between oligopolistic generating companies in a two-stage electricity market with high penetration of renewable resources. To this end, we assume a single futures market that is cleared prior to a spot market where the energy delivery takes place. We introduce different types of contracts in the futures market to evaluate their impact in the equilibrium market outcomes and how these depend on the level of renewable generation in the system. Moreover, since market participants are usually risk averse, a coherent risk measure is introduced to deal with both risk neutral and risk averse generators. The performance of the proposed equilibrium model and its main properties are tested through realistic numerical simulations.

■ TD-18

Tuesday, 14:30-16:00 - C112

Recent Perspectives and Advances in Statistics I

Stream: Data Mining and Statistics
Invited session
Chair: *Mujgan Tez*
Chair: *Vadim Strijov*
Chair: *Vincent Grollemund*

1 - Clustering and Outlier Detection by the EM Algorithm based on the Restriction Principle
Vedran Novoselac

Cluster analysis and outlier detection present important topics in data mining, and in most cases they are studied separately. In this work the joint problem of clustering and outlier detection is considered. The problem is observed for data that are modeled by a random sample whose distribution is a mixture of Gaussians. Considering the form of statistical modeling in outlier analysis which is based on a level of statistical significance of the tails of a observed density function; the problem is resolved by the restriction of the hidden variable of the well known Expectation Maximization (EM) algorithm. In that sense the adaptive framework is developed which effectively preserve the cluster's structure, or in other senses detect outliers. The general problem is set as the optimization of the proposed algorithm in terms of the cluster validity criteria. For that purpose, new clustering quality measures are proposed. It is established by experminetal reserach, which are conducted on various numerical examples that the proposed method possesses the convergence property. This method is emphasized in digital image processing for pattern recognition.

2 - Public funding recommendation using Machine Learning
Vincent Grollemund, François Delbot, Jean-François Pradat-peyre, Gaetan Le Chat

Public funding is a differentiating factor for compagnies who wish to fund their research and winning ones have a strategic advantage over the others. Applications are time-consuming and costly so there is a genuine need for companies to determine appropriate funding mechanisms. Currently, winning company data is limited and not sufficient to perform data mining and clustering without alleviating the risk of bias. Our approach focuses on the larger overall French company population, to understand the overall population data distribution. We use clustering methods and we match companies which have won research funding with resulting company clusters. This allow to strongly limit the number of public funding mechanisms to consider when looking for research funding. Available data has a low feature to sample ratio, which stems from one of K encoding of categorical data from location and business segment features. Dimension reduction methods perform poorly with mixed data types (specifically when the categorical states are exclusive). Our idea is to process the categorical data using economic a priori knowledge based on national statistics of financial statements. Categorical features are mapped to a numerical score using averaged financial statement features calculated for each region and business line. One of K encoding is replaced by five numerical features, which take into account the relationship between business segment and region location on financial statement elements.

3 - Identifying indicators of (non-)profitable customers: The Hinge Discrete Dantzig Selector
Dmytro Matsypura, Jessica Wai Yin Leung

Modern insurance data have evolved and so must the insurance industry. Given the massive scale of the data, it is tempting to change our approach to its analysis solely based on its size. Yet, to translate the data-intensive environment into data-enabled competitive advantage, one must carefully select the relevant and interpretable attributes to look into. An appropriate subset of attributes informs not only which potential customer is of high risk but also the premium pricing decisions and guides the formulation of loss reserving, marketing and customer management strategies. Leveraging the technological and algorithmic advancement of the last quarter-century, we present a mixed integer linear optimisation (MILO) approach to select the most relevant indicators of high risk insurance customers. We propose a novel high-dimensional classifier: The Hinge Discrete Dantzig Selector, which minimises the number of attributes in a model subject to a budget on the correlation between the variables and the errors. We demonstrate that the performance of the Hinge Discrete Dantzig Selector is superior to the existing popular approaches using synthetic and empirical data.

4 - Understanding Roadworks Vehicle Incursions Using Data Analytics
Zainab Riaz, Fahad Mehmood, Zeeshan Aziz

Vehicle incursions in roadworks' sites are gaining significant attention from highway authorities as these incursions pose extreme threat to the safety of road workers. Regardless of these incursions resulting in injuries or fatalities among road workers, any irrelevant or external interference such as a vehicle incursion in the roadwork's site is now being considered as an intrusion in the work of road workers and a threat to their and the equipment's safety. With the realization that these incursions should not be accepted as part of routine, efforts are being made by the UK highway authority to create awareness regarding the issue of incursions, to implement methods to reduce the risk of incursions and to encourage reporting and recording of incursions. This paper aims to study incursions through exploratory analysis comprising of visualizations and association rules to identify hot spots of incursions on the strategic road network of England. For this purpose, data regarding incursions such as date, time, location, severity, type and description of incursions are analyzed. The primary focus is to explore the data with reference to the severity, and intentional and unintentional incursions. Such exploratory analysis of the incursions data can highlight the aspects where the UK highways authority needs to focus on. This will eventually play a crucial role in the creation of safe working environment for the road workers.

■ TD-19

Tuesday, 14:30-16:00 - C115

Emerging Applications in Management Science

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: *A. Ismael F. Vaz*
Chair: *Guido Schryen*

1 - Parallel and High Performance Computing in Operations Research
Guido Schryen

Solving optimization problems with parallel algorithms has a long tradition in operations research (OR). Its future relevance for solving hard optimization problems in many practical fields, including finance, logistics and production, is leveraged through the increasing availability of powerful computing capabilities. We suggest a framework for computational parallelization in OR, which distinguishes four layers of parallelization: 1. the object of parallelization, 2. the algorithmic parallelization, 3. the computational parallelization, and 4. the performance of parallelization. We use this framework to systematically synthesize how the OR discipline has made use of modern parallel computing capabilities, including high performance computing capabilities, in the past decade. This synthesis provides an overview of recent advancements in OR across problems and methodologies by revealing, for example, how machine scheduling problems, flow shop scheduling problems, knapsack problems, traveling salesman and vehicle routing problems have been solved through the parallelization of branch-and-X methods, dynamic programming, and various metaheuristics. Based on our analysis, we use the abovementioned framework to identify those areas of parallel optimization in OR which require much more insights to exploit the huge potential that today's and future high performance computing offers for OR. We condense our findings in concrete research directions for parallel optimization in OR.

2 - Warranty parameters for two-dimensional policies with options to renew
Amitava Mitra

Certain consumer durable goods, such as automobiles, typically have a warranty policy that is two-dimensional in terms of time and usage. On purchase of the product, the manufacturer offers a warranty with specified values of the parameters. Some manufacturers may also provide an option to extend warranty during the initial purchase or later on expiration of the initial policy. Usually, the premium charged to extend warranty during the time of sale of the product is less than that charged on expiry of the initial warranty. A model is formulated to incorporate an objective function that represents net unit profit developed on the basis of expected warranty costs and income based on expected market share and premium to be charged for extending warranty. The decision variables are unit product price, the warranty policy parameters for both the initial and extended policy, and the premium to be charged to the customer who selects to extend warranty.

3 - The mediation role of supply chain integration on competitive capabilities
Eduard Gabriel Ceptureanu, Roy Cerqueti

In this article, we analyze the influence of supply chain integration on organizational performance. As a consequence, we introduced a proxy variable (i.e. supply chain integration), and we sought to analyze the ways in which organizational capabilities mediate the relationship between supply chain integration and organizational performance through the use of hierarchical regression analysis. Our results provide empirical evidence that the intensity of supply chain integration leads directly to improving organizational performance. This study reveals empirical evidence on the role of mediating organizational capabilities in managing the supply chain management.

4 - Optimal 3D printing of complex objects in a 5-axis printer
A. Ismael F. Vaz, Diana Pinho, Daniela Martins

Three-dimensional (3D) printing, also known as additive manufacturing (AM), has been emerged as an innovative technology to build complex structures, enabling increased design complexity and low-cost customization with a vast range of materials. AM capabilities contributed to a widespread acceptance of 3D printing in different areas such as aerospace, automotive, and other industries. However, some important issues need to be overcome and some limitations are pointed out to this architecture, namely in the printing of complex objects when support and low material roughness surface are needed.

In this talk a 5-axis printer with three traditional XYZ movements and two additional degrees of freedom in the printer table bed will be consider. These extra degrees of freedom (table bed rotation and inclination) will allow printing of more complex objects. We consider an approach which consists in the decomposition of complex parts into simpler sub-parts allowing each sub-part to be printed in an optimal way, by reducing the number of supports needed and attaining high final object quality due to lower material surface roughness. The decomposition of complex parts leads to an optimization problem where we aim to compute the optimal building sequence of sub-parts.

We provide exact and heuristic approaches for the optimization problem in hand. Several practical examples, with different complex objects, will be used to illustrate the proposed approach.

■ TD-20

Tuesday, 14:30-16:00 - C006

Numerical and Optimization Techniques Meet with OR

Stream: Numerical and Optimization Techniques Meet with OR
Invited session
Chair: Burcu Gürbüz

1 - A numerical scheme for solving a rumor propagation model
Burcu Gürbüz, Gerhard-Wilhelm Weber

Recently, spread of rumors in a population is investigated using models based on nonlinear ordinary differential equation systems by increasing interest. In this study, a numerical technique is introduced in order to solve this such system of equations. Error analysis is given with the details. Also, applicability of the method on this system is shown by the illustrative examples.

2 - Adversarial Risk Analysis for Obfuscation Attacks (AROA)
Alberto Redondo Hernández, David Rios, Joel Brynielsson, Edward Tjörnhammar

Code obfuscation incorporates methods to modify the binary code in order to built malware difficult to detect. At the present time, these techniques constitute two main forms: polymorphism and metamorphism. Polymorphism changes the binary maintaining one of the segments unaffected becoming highly vulnerable through anti- malware tools. Metamorphism utilizes advance obfuscation methods making use of code substitutions, dead code insertion, register renaming or flow control modification. It produces a new binary clone being less exposed for anti-malware tools. In this work, we present a model to detect metamorphism obfuscation attacks based on Adversarial Risk Analysis when common knowledge assumptions are not available. This novel approach models an adversary that is able to perform: poison attacks, which makes the algorithms learn wrong data; evasion attacks, which the adversary perturbs the data causing binary misclassification; and, inference attacks that obtains the limits of the algorithms. We illustrate the consistent results achieved on various adversarial settings and we sketch the probable future challenges.

3 - Optimizing O&M resource allocation for an asset portfolio under heterogeneous degradation and maintenance effects
Luis Dias, Luis Guimarães, Armando Leitão

Assets have a specific design life and, in many industries such as the utilities, a large share are reaching this age. Thus, unplanned maintenance is increasing leading to rising operation and maintenance (O&M) costs. Typical asset management approaches focus on maintenance optimization for a single asset by using condition-based maintenance which proves to be effective in different industrial applications. However, this type of approaches does not assure the best result for an asset portfolio since assets are inter-related and resource dependent. Recent developments in the field of asset management optimization have revealed the benefits of integrating all assets in a multi-asset system. Due to the inherent problem complexity researchers rely on simplifying assumptions, such as using the same degradation pattern and maintenance interventions effects for all the assets in the portfolio. Conversely, these assumptions lead to sub-optimal solutions with a limited fit to reality. To tackle these issues, we propose a novel mixed-integer optimization model, which receives as input each asset present and predicted condition. We aim to optimize resource allocation for maintenance scheduling and asset replacement. In this formulation, each asset can be subjected to different condition degradation rates and different maintenance interventions impact the asset condition. The objective is to achieve a homogeneous resource allocation while minimizing the net present value of O&M costs.

4 - A Pipeline Supply Chain Strategy based on Product Standardization to Minimize the Costs of Gasoline Supply Chain in Mexico
Rafael Carmona-Benitez, Hector Cruz

Mexico's gasoline demand forecast shows an increase for the future. But PEMEX (oil company owned by the Mexican government) does not have infrastructure to meet the Mexican gasoline demand. To meet the demand, in 2014, Mexico approved an energy reform that seeks to develop the energy sector. The reform obligates PEMEX to share pipelines and storage terminals to private companies creating two problems: one, sharing the storage terminals to store all different types of gasolines increases inventory costs; two, sharing the tube is counterproductive because interfaces are created producing mid-grade gasoline which can be sold when it is produced between two gasolines from the same oil company, but if not a transportation problem exists. The current solution to this problem is to transport mid-grade gasoline to a refinery, then apply a transmix refining method. The other solution is the aim of this study which is to design a supply chain strategy based on product standardization. The main goal is to minimize total costs and transfer the economic benefit to the final consumer. To validate the strategy, we propose a multi-product pipeline inventory-routing problem with transshipment with stochastic demand and variable lead time. The application of the mathematical model to the current Mexican supply chain optimizes the costs in 12.52%, and applying the strategy, a saving of 56.14% is obtained. The results of the study contribute to the legitimization of the Mexican energy reform.

■ TD-21

Tuesday, 14:30-16:00 - F101

Lot Sizing III - Multi-echelon lot-sizing models

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: Wilco van den Heuvel

1 - Optimizing material flows in a multi-period supply chain network with fixed costs - mathematical formulation and valid inequalities
Roland Braune

This contribution considers a multi-period network flow problem for strategic-tactical planning of material movements among plant locations of a manufacturing company. Transport capacities on edges can be allocated in integer multiples of a base capacity that corresponds to a single truck load. The number of truck loads that can be moved between two nodes in the network depends on the driving time and the vehicle's daily availability. Fixed costs arise from the transports' total time demand. Although the core of the problem bears resemblance to the network loading problem, which has already been studied extensively in the scientific literature, the dynamic multi-period nature of the overall scenario in combination with admissible intermediate storage of commodities and various additional custom constraints has not specifically been addressed so far.

Based on a time-expanded mixed-integer programming formulation, selected valid inequalities that have initially been designed for the network loading problem are adapted to properly fit in the multi-period context. The focus, in particular, is on cutset and multicut (e.g., spanning tree) inequalities, involving integer variables only. Computational experience gained from both synthetic (randomly generated) and real-world benchmark problem instances provide strong evidence for an effective strengthening of the LP relaxation of the problem's capacity formulation, thus making it possible to "project-out" the flow variables.

2 - Production planning problem with industrial symbiosis
Elodie Suzanne, Nabil Absi, Valeria Borodin, Wilco van den Heuvel

Waste accumulation and global warming are currently hot topics. To overcome these issues, new environmental regulations have been adopted by different organizations. In this context, we propose several models for the single-item lot-sizing problem, which integrates the use by a production unit of unavoidable production residues of another production unit, classified as by-products, forming a by-product synergy. During the production of a main product in the first production unit, a by-product is generated and used as raw material by the second production unit. This problem of industrial symbiosis is investigated for different kinds of storability of the by-product: (i) non-storable, (ii) unlimited storable and (iii) storable with a limited capacity. These problems being NP-Hard, we propose a Lagrangian relaxation based algorithm to solve them and show the efficiency of this method with some numerical results.

3 - Benders Decomposition for a Three-level Lot Sizing and Replenishment Problem with a Distribution Structure
Matthieu Gruson, Jean-François Cordeau, Raf Jans

We address a three-level lot sizing and replenishment problem with a distribution structure (3LSPD). We consider one production plant that produces one type of item over a discrete and finite planning horizon. The items produced are transported to warehouses and then to retailers using direct shipments. Each retailer is linked to a unique warehouse and there are no transfers between warehouses nor between retailers. The objective is to minimize the sum of the fixed production and replenishment costs and of the unit variable inventory holding costs. We use a Benders decomposition approach and develop a Benders based branch-and-cut algorithm to efficiently solve both a deterministic and a stochastic variant of the uncapacitated case of the problem. We take advantage of the substructures identified in the decomposition and design efficient procedures to solve the different subproblems obtained. We also propose several computational enhancements to speed up the solution processes. In particular, we develop an algorithm that allows us to derive a Pareto-optimal cut without solving an auxiliary problem nor using a general purpose solver. We finally perform numerous computational experiments to assess the performance of our decomposition approach and see the impact of our enhancements. The Benders based branch-and-cut algorithm we propose clearly outperforms CPLEX for solving large deterministic instances and for solving stochastic instances.

4 - Two-Echelon Lot-Sizing with Asymmetric Information and Continuous Type Space
Wilco van den Heuvel, Rutger Kerkkamp, Albert Wagelmans

We analyse a two-echelon discrete lot-sizing problem with a supplier and a retailer under information asymmetry. We assume that all cost parameters are time independent and that the retailer has single-dimensional continuous private information, namely either his setup cost or his holding cost. The supplier uses mechanism design to determine a menu of contracts that minimises his expected costs, where each contract specifies the retailer's procurement plan and a side payment to the retailer. There is no restriction on the number of contracts in the menu. To optimally solve this contracting problem we present a two-stage approach, based on a theoretical analysis. The first stage generates a list of procurement plans that is sufficient to solve the contracting problem to optimality. The second stage optimally assigns these plans to the retailer types and determines all side payments. The result is an optimal menu with finitely many contracts that pools retailer types. We identify cases for which the contracting problem can be solved in polynomial time and provide the corresponding algorithms. Furthermore, our analysis reveals that information asymmetry leads to atypical structures in the plans of the optimal menu, e.g., plans violating the zero-inventory property. Our solution approach and several results are directly applicable to more general problems as well.

■ TD-22

Tuesday, 14:30-16:00 - F102

Social Sustainability in Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Ana Barbosa-Póvoa

1 - Quantifying Social Sustainability in OR Models for Strategic Network Design
Lukas Meßmann, Victoria Zender, Christoph Helbig, Axel Tuma, Andrea Thorenz

Incorporating the social pillar of sustainability is a challenge in quantitative supply network design. Against this background, we review this field with respect to social indicators used quantitatively in model objective functions or constraints. In particular, we examine 1) what social aspects using which indicators are considered, 2) how their selection is justified, 3) how they are incorporated into what OR models, and 4) whether the industry sector of case studies influences the choice of indicators. With this extensive study, we strive to contribute to the development of a more coherent set of applicable aspects and to increasing homogeneity in the way that these aspects are incorporated into quantitative models. Pertaining to these results, we integrate the state of the art in social optimization into a MILP model for reverse network design, applied to the case of Waste Electric and Electronic Equipment (WEEE) recovery in the European Union. On par with and analogous to economic and different environmental objective functions, the social benefit is maximized. Depending on the dimension a socially optimal network is compared with, results can either be largely congruent (e.g. global warming, ionizing radiation), partially conflicting (e.g. economic, land use), or contrary (e.g. mineral resource scarcity), which is resolved by ϵ-constraint.

2 - Current practices of CSR around the globe: An exploratory text mining study
Charlie Lindgren, Asif Huq, Yujiao Li, Kenneth Carling

There is extant research on theorization, conceptualization, determinants, and consequences of Corporate Social Responsibility (CSR), however, what firms actually include in their CSR or Sustainability reports are much less covered and predominantly case studies of individual firms. In this paper, we take a holistic view and simultaneously explore what firms around the globe currently report in these reports. To do so, we exploit tools of harnessing big-data and machine learning techniques to analyze a large corpus of text data (i.e. CSR reports of the firm). Data were collected through web scrapping aggregate data points (i.e. html links) from the Global Reporting Initiative (GRI) database, a strategic partner of UN Global Compact. 12908 reports out of 36192 links were successfully downloaded of which 7881 were reported in English for the years 1999 to 2017. To explore what firms currently reports in these reports we used the unsupervised Bayesian machine learning approach Latent Dirichlet Allocation (LDA) developed by Blei, et al. (2003). GRI is the most widely used reporting format for such reports worldwide thus CSR reports are expected to become more homogenous over time. However, in preliminary results of 1769 reports reported in English for the year 2016, we find there is a great variation of dominant topics across the different continents for the various industries and firm sizes. To offer a comprehensive view of the results we have developed a freeware web app.

3 - From Adoption to Incorporation of Supplier Codes of Conduct: A Framework based on Diffusion of Innovation Theory
Johannes Heller

Supplier codes of conduct (SCoCs) are considered to be the most important tool for establishing social sustainability in supply chains. Typically, suppliers signalize their adoption with a signed agreement. However, the adoption of SCoCs often remains of symbolic nature. For SCoCs to become effective, they have to be incorporated by suppliers. Incorporation can be achieved by implementing management systems which support the SCoC. We propose a framework which consists of four constructs for determining the degree of SCoC incorporation by suppliers. Acceptance provides insights on how knowledge of a SCoC is disseminated within the suppliers' organization. Routinization focuses on measures that enable the application of a SCoC. Assimilation is concerned with the spread and utilization of a SCoC across different organizational processes and functions. External diffusion examines how a SCoC is distributed to other supply chain members. All constructs, which are derived from diffusion of innovation theory and research on internal codes of conduct, focus on assessing the existence of appropriate management systems and their effectiveness. Practitioners can apply the framework to classify suppliers and formulate future requirements. Scholars can use it to further investigate the topic of SCoC implementation by suppliers, which has been treated as a black box so far.

4 - Supply chain design with societal concerns
Bruna Mota, Ana Carvalho, Maria Isabel Gomes, Ana Barbosa-Póvoa

In this work a methodological approach based on multi-objective mixed integer linear programming is proposed to support decision makers in strategic supply chain decisions with societal concerns. The goal is to contribute, through network design, to increased socio-economic equity in the European Union. Four objective functions are implemented: Net Present Value to evaluate the economic performance of the supply chain; number of direct jobs created, as it is typically implemented in the current literature; and the other two objective functions couple job creation with two socio-economic indicators based on Gross Domestic Product and Unemployment Rate. The objective is to stimulate economic growth and/or job creation in regions that need it the most, without compromising the economic performance of the supply chain. The methodological approach is applied to a representative European case-study. A solution approach for the multi-objective problem is also developed and applied to the case-study. It was concluded that even though impacted, the economic performance of the supply chain can sustain the proposed objectives. Governmental economic incentives can be provided to compensate such decrease in the economic performance.

■ TD-24
Tuesday, 14:30-16:00 - F103A

Guaranteed service models

Stream: Supply Chain Management
Invited session
Chair: Ton de Kok

1 - Safety stock placement in dual-sourced supply chains: a successive approximation approach
Stefan Minner
We present an extension of the guaranteed service approach to safety stock placement in supply chains including multiple sourcing options and service level constraints and present a new solution approach based on linear programming with successive approximation and performance guarantees.

2 - Explicit demand propagation for Guaranteed Service Models
Jörg Rambau
The Guaranteed Service Model (GSM) for multi-echelon inventory control relies on the fact that, because of assuming a base-stock policy without lot-sizing, the end customer demands propagate upstream unaltered immediately. Thus, the demands at internal nodes do not depend on downstream decisions. This drastically changes in the presence of outsourcing or multiple sourcing opportunities. If there are outsourcing options for the decision maker, the upstream demand is smaller than predicted and depends on the outsourcing decision. This is, e.g., relevant for refinements of the GSM like the Stochastic GSM (SGSM) that explicitly account for operational flexibility, i.p., outsourcing. Because of the demand propagation problem they systematically overestimate costs, and, thus, their model-optimal solutions may not have minimal cost with respect to the true demand propagation. In this talk a first guaranteed service model with explicit demand propagation is presented for linear demand bounds. The model is based on the Mixed-Integer Linear Programming formulation of the GSM by Magnanti et al. (2006). An illustrative example with outsourcing is shown, where the new model is able to find a solution with almost 40% lower actual cost compared to the existing approximative model without explicit demand propagation. We additionally present an experiment with randomized data for ten-node random networks showing a similar cost saving potential on average.

3 - Order smoothing in supply chains under the guaranteed-service approach
Kunal Kumar, Tarik Aouam
The existing safety stock placement models under the guaranteed-service approach typically assume supply chains to follow a periodic-review base-stock policy. Under this policy, the demand variability from the end-stages is transmitted to utmost upstream, which results in high safety stock costs. In this work, we relax this assumption by allowing stages to smooth their replenishment orders based on the exponential smoothing rule. Order smoothing reduces demand variability at the upstream stages and lowers their capacity and inventory costs. At the same stage, it increases inventory variability at the ordering stage and incurs high holding costs. This work analyses the various trade-offs in the model and characterizes the impact of service times on smoothing parameters, and vice-versa. We present bounds on the optimal smoothing parameters and guaranteed service times. These bounds are used to develop two efficient genetic algorithms (GAs) - based solution approaches. The first approach combines an existing

dynamic program with GA to solve for supply chains with a spanning-tree structure. The second method is a pure GA and builds on the proposed bounds to solve for general acyclic network structures. Computational studies conducted on real-world instances from the literature demonstrate that the proposed algorithms provide good solutions in reasonable CPU times. Numerical studies indicate a significant economic value of smoothed ordering and analyze the factors influencing this

4 - Drivers and Enablers for the successful implementation of a Supply Chain Management policy in State Owned Entities in South Africa
Tebogo Moromane, Ozias Ncube

Implementation of the supply chain management policies and procedures is a challenge in the government and in state owned entities. The purpose of this research was to identify the drivers and enablers for the successful implementation of supply chain management policies and National Treasury regulations and guidelines within the state owned entity environment so as to develop an appropriate framework. An extensive literature was performed that identified possible drivers and enablers. A mixed methods approach was utilised to assess suitability, relevance and practicality of these. The qualitative part focussed on having in-depth interviews with the senior executives who drive strategy implementation within a regulated environment, while the quantitative part focussed on the implementation of the policy (both from supply chain analysts and internal stakeholders). On analysis key drivers were identified, and suitable enablers unpacked. On this basis, a framework is proposed, which is deemed appropriate for successful implementation. The framework provides clarity for deriving supply chain efficiencies within an acceptable governance structure.

■ TD-25

Tuesday, 14:30-16:00 - F104

Scheduling in Production Systems

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: Eduardo Salazar

1 - Scheduling and loading problem for multiple, identical dry kilns
Maria Anna Huka, Manfred Gronalt

A heuristic approach has been developed to optimize the scheduling and loading problem for multiple and identical kilns in large softwood sawmills, creating optimal kiln allocation plans according to existing production specifications. The heuristic takes stacking and placement restrictions into account and calculates the optimal position, time and kiln for each package. The aim is to minimize the overall tardiness for drying all lumber packages with regard to technological and capacity constraints. Several heuristic approaches are illustrated and tested against actual production data. They begin by grouping packages of lumber according to board thickness, each group being characterized by a range of thickness. Then the packages within each group are sorted into potential batches according to release time and the best potential batch is selected and assigned to a corresponding kiln. After all packages have been scheduled solution improvements are attempted via tabu search. Even under the given conditions, a significant improvement in total tardiness and kiln utilization can be achieved. Further improvements are possible by: drying of different lumber assortments in one batch, outsourcing of drying of special assortments or investment in additional kiln units for drying smaller volumes within more flexible time windows.

2 - On designing dispatching rules for dynamic collaborative environments
Cristiane Ferreira, Gonçalo Figueira, Pedro Amorim

The emergence of Human-Robot teams (HRT) in assembly lines has brought new challenges to decision-making. On the one hand, these collaborative environments benefit from the distinct strengths of the resources: while robots are precise, humans are flexible and efficient in complex tasks, and on the other hand, the presence of humans introduces uncertainty into the execution of tasks. This is particularly important given that synchronisation is an essential aspect of HRTs, as the resources must execute some tasks simultaneously. In addition, there is an increasing degree of customisation of products, making assembly lines even more dynamic. All these facts motivate the development of flexible methods to production scheduling, for the proper adaptation of schedules to the unexpected events and disruptions that occur in real-time. The literature has shown that dispatching rules are efficient methods for dynamic scheduling. This work presents efficient rules for dynamic and collaborative environments, automatically designed by the use of Genetic Programming. The rules are evaluated by simulating HRTs in assembly lines, considering different performance metrics. We also analyse the influence of due date tightness, uncertainty level and different HRT characteristics in the evolved rules results. Finally, we compare the performance of the generated rules to benchmark dispatching rules and methods used in robotics literature.

3 - Lean Production Planning Transformation and Goal Programming Approach for a Hybrid Scheduling Problem
M Arslan Ornek, Serhat Karakutuk

Companies use different production policies to ensure customer demands are satisfied in time. Among these policies Make to Order (MTO) and Make to Stock (MTS) are mostly and widely used. To track the performance of production policies some important Key Performance Indicators (KPIs) related to production control and management are On Time Delivery (OTD), machine or line productivity (OEE - Overall Equipment Efficiency), optimization of WIP level between workstations, customer satisfaction i.e., prioritization of customer orders according to requirements of customer and backlog minimization. In this study, a real life production management problem is described, modelled, and solved to improve customer delivery rate and production planning using lean production tools. Currently, the firm uses Assembly to Order (ATO) for managing assembly and MTS for semi-finished materials. The problems encountered of this system are low customer service level, high level work in process (WIP) between operations and efficiency losses. Therefore, the goals of this study are to increase efficiency (OTD, OEE, and customer satisfaction) and decrease WIP and backlog quantity level by improving service level given to customer. We propose a mathematical formulation based on goal programming and two heuristic algorithms. Then, we discuss numerical results and provide our final remarks and conclusions.

4 - A MILP Model for solving a Generalized Steelmaking and Continuous Casting Scheduling Problem
Eduardo Salazar

A MILP model for solving a generalized Steelmaking and Continuous Casting scheduling problem is presented. A given set of production orders (each production order defined as a set of batches to be cast continuously on a given machine), must be produced in an integrated steel plant. The general structure of the production system considers an arbitrary number of machines at each stage (converters, refining stations and continuous casting machines), producing orders of several steel grades and types (e.g. slabs and billets). Optimization criteria such as productivity (makespan) and the satisfaction of technological constraints such as continuity between batches of the same production orders and in process time of liquid steel are discussed. The modeling approach allows small sized instances of the problem to be solved, so further research on metaheuristics solution approaches are discussed.

■ TD-26

Tuesday, 14:30-16:00 - F106

OR and Ethics and Societal Complexity II

Stream: OR and Ethics
Invited session
Chair: Cathal MacSwiney Brugha

1 - The Trimurti of Multiple Criteria Decision Analysis (MCDA) Methodologies within a Qualitative Analysis (QA) process.
Malcolm McKiggan

ABSTRACT Examination of the three primary constituents of Qualitative Analysis (QA), defined as Individualism, Social Communion and Empowering Institutions are the Trimurti of QA and should be used as the framework for analysis of complex social systems at Strategic, Operational and Tactical levels to properly develop the Problem Definition and identify options. By giving relative social context to primary data they support the construct of a suitable model highlighting the essentials of fundamental knowledge of the issues, specific domain experience within these issues and based on an accepted, communal based, ethical social justice system prioritise a Multiple Criteria Decision Analysis (MCDA) capable of traceability of process and justification of outcomes supported by a quantifiable sensitivity analysis.

2 - Using simulation for verifying robust solution of Emergency Treatment Sites location after earthquake
Simona Cohen Kadosh, Zilla Sinuany-Stern, Yuval Bitan

The sudden nature of an earthquake causes massive infrastructure destruction, casualties, chaos and panic among the population. In most cases the initial rescue and evacuation activities of victims are done by family members, neighbors and passing-by volunteers. The standard framework of earthquake preparation policy in Israel defined the necessity of deploying Emergency Treatment Site's (ETS) as part of disaster logistics. These treatment sites aim to provide medical first aid during the first 72 hours to moderate and light condition casualties. We assume that during those first hours after nature disaster, the lack of information regarding the locations of ETS's, may affect the actual evacuation time from destruction sites to the emergency treatment points. To improve the ETSs deployment location, our research includes an experiment that evaluates the influence of uncertainty (resulting from the missing information about distances people need to walk from destruction site to ETS's) on evacuation time while carrying weights. The results of this experiment will be used for Monte Carlo simulation verifying the best location of ETS deployment and its robustness. The research will provide recommended ETS's locations for a given earthquake scenario that will achieve maximum treated casualties at minimum duration time under given constraints. This planed facilities deployment can also help reducing uncertainty of ETS deployment policy as part of disaster preparedness.

3 - Cultural Research in the Operations Management Field
Richard Metters

OR models are typically thought of as "universal". However, one cause of non-universality is national culture.

We summarize and categorize Operations Management (OM) research on two inter-related types of "culture": exogenous, or national culture and endogenous, or organizational culture. OM cultural research is far less than one percent of total OM research. We posit that of that small amount, much of OM cultural research is based on numerical approaches that have questionable validity. Qualitative work is highlighted. In addition to being a guide for research, this article is meant to provide substantive examples for teaching the importance of culture in OM.

■ TD-27

Tuesday, 14:30-16:00 - F107

Optimization in Social Networks

Stream: Network Analytics and Optimization
Invited session
Chair: Mario Ruthmair

1 - Influence Maximization in Social Networks under Deterministic Linear Threshold Model
Dilek Gunnec, Furkan Gursoy

We define the new Targeted and Budgeted Influence Maximization under Deterministic Linear Threshold Model problem and develop the novel and scalable TArgeted and BUdgeted Potential Greedy (TABU-PG) algorithm which allows for optional methods to solve this problem. It is an iterative and greedy algorithm that relies on investing in potential future gains when choosing seed nodes. We suggest new real-world mimicking techniques for generating influence weights, thresholds, profits, and costs. Extensive computational experiments on four real network (Epinions, Academia, Pokec and Inploid) show that our proposed heuristics perform significantly better than benchmarks. We equip TABU-PG with novel scalability methods which reduce runtime by limiting the seed node candidate pool, or by selecting more nodes at once, trading-off with spread performance.

2 - The Influence Maximization Problem: Extensions, Efficient Solution Methods and Challenges
Evren Guney

The Influence Maximization Problem (IMP) is defined as finding the most influential subset of individuals out of a large stochastic social network so that the maximum number of members of the network is influenced. As social networks are a very significant part of our daily lives, IMP has been attracting great interest among researchers and practitioners recently. In IMP, it is assumed that the spread of influence follows certain popular diffusion models, such as independent cascade or linear threshold models which leads to the existance of a submodular objective function. Benefiting from this property, most of the researchers apply greedy based heuristics that guarantee a (1-1/e) performance guarantee. Since the network is stochastic exact solution methods are intractable for even small networks, therefore sampling based strategies are used for approximate solutions. In this study, we focus on various varients of IMP, such as multi-network IMP, context-based IMP, network value maximization and similar extensions. Next, we explore the state-of-the-art solution methods, arising challenges and possible research directions for these extensions. We complete our work with numerical examples to illustrate the performance of various solution methods and bottlenecks.

3 - Interdiction for Cyber-epidemics in Online Social Networks
My Thai

In this work, we examine a new optimization problem in online social networks (OSNs), called Suspension of misinformation Spreading (SOS). Given a social network and an information diffusion model, SOS seeks to remove k edges in the network so as to minimize the infection spread from the initially infected nodes. This problem was motivated by the fact that cyber-epidemics have caused significant economic and political consequences due to the fast and wide spreading of misinformation, empowered by OSNs. Such a widespread of the untruth and propaganda has potential to pose serious threats to global security. The World Economic Forum has listed massive misinformation as one of the main threats to our society.

In this work, we provide an exact solution to SOS and a scalable approximation algorithm, which can run on billion-scale network with a tight performance guarantee of 1 - 1/e. The power of our solution lies in a suite of novel techniques, including a new importance sampling, partially lazy greedy techniques, and advanced concentration analysis to reduce the number of required samples as much as possible.

4 - Large-Scale Influence Maximization via Maximal Covering Location
Mario Ruthmair, Evren Guney, Markus Leitner, Markus Sinnl

Influence maximization aims at identifying a limited set of key individuals in a social network which spreads information based on some propagation model and maximizes the number of individuals reached. We show that influence maximization based on the probabilistic independent cascade model can be modeled as a stochastic maximal covering location problem. A reformulation based on Benders decomposition is proposed and a relation between obtained Benders optimality cuts and submodular cuts for correspondingly defined subsets is established. In a computational study our branch-and-cut approaches outperform the state-of-the-art approaches for influence maximization by orders of magnitude.

■ TD-28

Tuesday, 14:30-16:00 - G102

AI, Blockchain and other tech innovations in Economics and Finance

Stream: Blockchain and Cryptocurrencies: Economic and Financial Challenges
Invited session
Chair: *Emanuela Raffinetti*

1 - Using expert ratings to predict ICO success
Romi Kher, Gianna Figà-Talamanca

Startups and small and medium sized enterprises (SMEs) face barriers in accessing capital markets and equity financing options. Crowdfunding has become more popular but its impact is often limited by amount raised and geography. This paper examines whether these restrictions can be overcome by blockchain-based initial coin offerings (ICOs). Analyzing a dataset of 4000 ICOs, we provide an empirical analysis of the phenomenon and determine how alignment of founder expertise, technology usage and product validation lead to ICO success. Using independent expert ratings as a proxy for external validation, we find that pre-ICO expert ratings are a good predictor of funding success.

2 - Robot advisory asset allocation through network models
Paolo Giudici

Automated digital consultancy platforms ("Robot advisors") is rapidly expanding, particularly because of the advances in the ap- plication of artificial intelligence in finance, and to the diffusion of alternative, "crypto" assets. Robot advisors may reduce costs and improve the quality of the service, making user involvement more transparent. However, they may also involve higher risks, among which compliance risk: the dan- ger to perform an asset allocation that underestimates investors' risk profile. In this paper we show how artificial intelligence can be used not only to improve robot advisory services but also to improve risk mea- surement. In particular, we demonstrate how random matrix theory together with correlation network clustering can be used to construct investment portfolios that correctly take high dimensional correlations into account. To demonstrate the advantages of our proposed model we employ the observed returns of a large set of Exchange Traded Funds (ETFs), which we believe quite representative of the activity of robot advisors.

3 - A rank-based measure to prioritise cyber risks
Emanuela Raffinetti, Paolo Giudici

A very crucial issue when dealing with the use of statistical and machine learning methods in Fintech applications is the construction of predictive accuracy diagnostics able to mitigate the risk of taking wrong actions. The motivation of our proposal is to further develop a more general measure, based on the distance between the observed response variable values and the same observed values ranked according to the corresponding values predicted by a given model. The measure, that we call Rank Graduation index (RG), can be used regardless of the nature of the response variable and is found quite effective in its application to cyber risk measurement. The main problem that arises in cyber risk measurement is indeed the lack of data, as the victims are not very willing to disclose such data. However, while the original continuous loss data may not be available, ordinal data that organise the observed loss frequency into severity classes may be so. This requires using ordinal data modeling techniques and, in particular, to rank the severity levels according to their level of importance. In the paper we propose an extension of the RG index to the ordinal context and, therefore, suggest a general way to prioritise cyber risks that is a function of their ranks. The proposed measure is validated through a real application that concerns cyber risk data collected at the worldwide level, classified by type of attack, victim and country of occurrence.

■ TD-29

Tuesday, 14:30-16:00 - C118

OR and the Arts and Sciences

Stream: OR and the Arts, Creativity
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Milagros Baldemor*
Chair: *Olabode Adewoye*

1 - Operational Research methodologies for the Pompei Archeological Park
Antonio Sforza, Maurizio Boccia, Claudio Sterle, Massimo Osanna, Luana Toniolo, Alberto Bruni

Pompei Ruins constitute a unique set of civil and private buildings, monuments, sculptures, frescoes and mosaics. With its 0.66 square kilometer the Archeological Park of Pompei (PAP) is one of the biggest archeological sites in the world, recognized by UNESCO as World Heritage Site, with 3.5 million of visitors per year. PAP subscribed a framework agreement with University "Federico II" of Naples to develop a scientific cooperation aimed to promotion, accessibility and dissemination of the site. In this context a research agreement with the Department of Electrical Engineering and Information Technology has been defined, devoted to identify and apply Operational Research models and methods to support the service management of the Park on two issues: guidance of the visitors and internal security. The first issue has been tackled as a TSP or an Orienteering Problem, to design a visitor path considering their needs and preferences in terms of entrance/exit points, typology of the internal sites, thematic paths, with the constraints on available time, path length, time windows of the sites. This optimization module will become the core of an app able to find the best customized visit route, based on the dynamic database of the Pompei Ruins. The second issue has been approached in terms of visibility and covering analysis of the camera surveillance system already implemented in the park. Results obtained will be presented together with some work and research perspectives.

2 - Classification and Generation of Digital Marble Art (EBRU) by revisiting OR via Deep Learning
Gerhard-Wilhelm Weber, Meltem Atay

In this study we introduce a novel data collection of paper based on digital copies of traditional Turkish art named as Ebru (marbling). In this dataset there are 5 sub-classes of Ebru styles and about 200 samples per class; the total number of data is 1000. Ebru data were gathered from non-copyrighted digital copies of the real Ebru collections. To introduce this dataset we used several supervised classification methodologies from machine learning and deep learning literature. Our best performing method is based on transfer learning; pre-trained and fine-tuned Inception-Resnet V2 model for 500 epochs using Adam optimizer with learning rate set to 0.0001, nesterov momentum 0.9, we obtained test accuracy of 92% and 0.92 loss. We also propose a novel architecture (SEDNet) to classify Ebru Dataset based on inception modules; it is an optimized-shallow version of Inception-Resnet V2 architecture. Our best performing model bases on transfer learning approaches with test accuracy of 92% and 0.46 loss. SEDNet is the unique model which we developed for classification task of this kind of art, resulting in test accuracy of 56% and 3.57 loss. We also developed novel strategies of generating new digital Ebrus by approaches of generative adversarial networks and we developed a novel architecture named as SEDGAN, specifically to generate digital Ebru art. This study is the first ongoing research on traditional art generation studies by our research group.

3 - Multimodel Selection for Classification Problems with Time Inhomogeneity
Alexander Aduenko, Vadim Strijov

The problem of multimodel selection for classification problems is considered. First, we consider static multimodels, which are used to handle inhomogeneity in features' space, i.e. the situation when features' weights depend on the features' values. Though such a multimodel is an interpretable generalization of a single model case, it can contain large number of similar models, which leads to a poor performance and lack of interpretability. Several pruning algorithms are constructed based on the suggested method for statistical model comparison, which allow improving classification quality and ensuring a multimodel is adequate. In order to prevent degradation of forecasting quality with time due to dynamic nature of relation between features and target variable, we introduce time-evolving multimodels, which have their parameters changing with time. The pruning methods are generalized to construct adequate time-evolving multimodels. Several computational experiments show significant improvement in classification quality for real datasets and substantial multimodel size reduction.

■ TD-30
Tuesday, 14:30-16:00 - C007

Emerging Applications in Data Science and Optimization

Stream: Data Science Meets Optimization
Invited session
Chair: Kevin Tierney

1 - Optimizing tool service life using tool vibration monitoring
Johannes Pan, Clemens Gutschi

Numerous operations in manufacturing industry include machining activities, e.g. drilling, milling, turning, honing and more. This not only removes material from the work piece, but also wear the tool over time. Service life determines when the tool is replaced or comes to the revision. The service life of the tool is difficult to calculate precisely due to the different influences that the tool is exposed during work and thus results in a certain fluctuation range. Too early or too late intervention increases the setup time or is reflected in lack of part quality in case of too late intervention and is therefore costly. One of the keys to achieving maximum productivity in the use of tools is the individual determination of the condition of the tool over its service life for each individual. In this paper we present a procedure to optimize the tool service life by analyzing vibrations to determine the actual tool wear. Fast Fourier transform and order analysis are utilized for extracting features of the time series. Redundant features are investigated and filtered by applying a regression analysis over several real-world datasets. Modeling the dependence of extracted features on the tool wear is done by machine learning. The feasibility of describing the increasing tool wear through vibration measurement allows to optimize the tool service life. Concluding, the feasibility of describing the tool wear through vibration measurement will be demonstrated.

2 - Analytics and Optimization for FTE Allocation in IBM Global Technology Services
Ali Koc, Brian Quanz, Ajay Deshpande

IBM Global Technology Services (GTS) manages hundreds of accounts each of which is served at various competency levels. Change requests, problems, service requests, and incidents are among the ticket categories that need to be handled at each competency level. Slow response to tickets cause SLA violations and increase violation costs. Ticket volumes and FTE (full time equivalent) are two levers that affects violation risks. We address the problem of optimal FTE allocation for reducing ticket violation risks and total FTE cost across multiple ticket competency levels. The problem consists of a learning phase, a forecasting phase, and an optimization phase. We develop multiple data science and machine learning algorithms and validate them to relate ticket violation risks to ticket volumes and FTE levels. A forecasting algorithm addresses ticket volume prediction in upcoming periods. A global nonlinear optimization algorithm finds optimal FTE levels that both minimize ticket violation risks and FTE costs. We use and test the overall solution over multiple GTS accounts.

3 - Assortment Optimization for Airline Ancillary Revenue Management
Ravi Kumar

We consider the problem of displaying optimal ancillary assortments to airline customers. The airline may have two objectives in mind while designing such systems : maximizing revenue from ancillaries or maximizing the conversion rate. We compare the performance of multiple methods for estimating ancillary purchase probabilities and finding the optimal offer sets based on product and customer features. In particular, our main motivation is to compare standard machine learning approaches with the well-known multinomial logit (MNL) model. We evaluate the performance of these methods using a simulation test bed which is tuned based on real customer datasets.

4 - Machine learning predicts outcomes of phase and possession-play in Rugby Union
Neil Watson, Ian Durbach, Theodor Stewart

The majority of performance analysis in sports has traditionally adopted a reductionistic approach in developing aggregated univariate measures of performance. In Rugby Union, few studies have attempted to develop measures of performance that capture the complexity of the game. To date, there are no studies in rugby that model the sequential nature of the game, and only a handful of studies have attempted to analyse the sequential nature of other invasion sports. This study makes important contributions to this gap in the literature. We use machine learning to model the sequences of in-game actions, with their field location, in to predict several binary outcomes of interest. We consider several convolutional and recurrent neural network architectures and compare the performance of these networks against that of a feed-forward multilayer perceptron as a baseline. We demonstrate that some of these models are capable of achieving high prediction accuracy, specificity and sensitivity across all the outcomes. We experiment with tuning the architecture and hyperparameters of the best performing model to improve its performance further. Furthermore, we glean valuable insight from the best performing model by (a) analysing what information it uses to make its predictions, and (b) conducting a what-if analysis by simulating and permuting sequences of actions and field locations to investigate which tactics yield the highest probability of achieving the desired outcome.

■ TD-31
Tuesday, 14:30-16:00 - G108

Workforce Scheduling at the Emergency Department

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Roberto Aringhieri

Chair: *Masoumeh Kazemi Zanjani*

1 - Staff Scheduling at an Emergency Medical Service: A meta-heuristic approach
Katrin Munzenrieder, Inês Marques

The goal of automated staff scheduling is to create fair and efficient work timetables to satisfy an organizations' demand while saving time and money. Numerous constraints, such as legal and contractual regulations as well as personal preferences, need to be considered to obtain feasible and pleasant schedules. Although the topic is widely studied in the literature, the number of implemented solution methods in Emergency Medical Services (EMS) is low. As shortages have a direct impact on the quality of care, efficient scheduling is crucial. Moreover, this is a new staff scheduling problem in the EMS as dispatch centers and emergency vehicles share the same workforce. It is motivated by the Portuguese National Institute for Medical Emergencies (INEM). Schedules must be generated for ca. 290 heterogeneous skilled staff members in different teams, working in different locations. Currently, the schedules are built manually, which is time-consuming and produces considerable administrative work to two emergency technicians overseeing this task. Two meta-heuristics are proposed to solve this staff scheduling problem in a reasonable time. The performance of both approaches is compared to understand which one should be embedded in a decision support system implemented at INEM. Finally, the solutions are compared with an actual INEM schedule and the advantages of its use in a real-life setting are explored.

2 - A Cuckoo Search Algorithm for Staff Scheduling at an Emergency Medical Service
Mariana Cunha, Inês Marques, Ana Barbosa-Póvoa

Nowadays, as cost consciousness and social benefits for employees are becoming increasingly more important to businesses the personnel scheduling area arises with greater importance, not only in economic terms, but also on social benefits. But staff scheduling has been a time-consuming task for companies' employees for a long time. Schedules are not only hard to construct but, often, result in feelings of inequity within the workforce. This work proposes the adaptation of the cuckoo search (CS) metaheuristic algorithm for the staff scheduling problem. CS algorithm is a recently developed nature-inspired, population-based metaheuristic. As a randomization technique, Lévy flights are used providing a good balance between exploration and exploitation. Furthermore, to improve the performance of the CS algorithm, a constructive heuristic is developed to provide the initial solution. The proposed method is applied to an Emergency Medical Service (EMS), with the objective of meeting demand, respecting working time regulations and worker preferences. Worker's skill sets and shifts are also considered in this problem. Results are compared with state-of-the-art approaches.

3 - A Simulation Optimization framework for Physicians Scheduling in Polyclinics
Masoumeh Kazemi Zanjani, Mohammad Tohidi, Ivan Contreras

Reducing patient wait-times and resource expenses are essential factors in health delivery systems. This paper presents a simulation-optimization (SO) framework for physicians scheduling in an outpatient polyclinic under uncertain arrival pattern and treatment time of patients. Our proposed methodology relies on the integration of a mathematical optimizer, an enhanced Simulated Annealing (SA) algorithm, with a discrete-event simulation kernel into a common programming language. In particular, our SO framework aims to improve the quality of the incumbent solution in the SA algorithm via implementing two enhancement strategies. The first strategy is to employ a non-linear mixed-integer-program to approximate the PSP in order to generate a high quality initial feasible solution. This is achieved via modeling the polyclinic under investigation as a D/M/1 queue and approximating the expected patient wait-time with an analytical (non-linear) function. The second strategy relies on introducing a diversification mechanism within the SA algorithm. Our numerical results based upon the data provided by a polyclinic in a university health center in Montreal, Canada, confirmed the significance of incorporating stochastic functions such as patient wait-time and physician overtime into PSP. Further, the optimization search routine developed in our SO model outperforms the existing search routines embedded into commercial SO software packages in terms of solution quality and CPU time.

■ TD-33

Tuesday, 14:30-16:00 - Q005

Modelling and Optimisation in Logistics I

Stream: Dynamics and Games
Invited session
Chair: *Jie Deng*

1 - An efficient rough set based approach to improve multi-temperature operations for a cold chain delivery
Teng-Sheng Su

Nowadays the chain store to fulfill customers' order in the agricultural product, fresh provision retailer, and restaurant industry has risen widely. Designing an efficient operational approach of the order-picking, package, and delivery in a low-temperature environment enables distributers to reduce product defects, save energy, and increase inventory turnover. Therefore, it is vital to design an intelligent order consolidation model for keeping commodities within a suitable temperature level and high quality during the entire delivery process in the cold chain picking system. In this study, a rough set based analysis approach adopted to consolidate and sort commodities according to the decision table comprised of condition and decision attributes is developed. A multi-temperature setup phase synchronization (MSPS) model is then proposed to solve the concurrent loading and delivery problem for multi-commodity with multi-temperature. An empirical example is given to illustrate the proposed strategy, which is capable of assisting distributors to sort out their physical supply problem more efficiently in the cold chain.

2 - An agent-based simulation model for dynamic railway seat allocation
Jiana-Fu Wang, Zih-Ming Li

Although dynamic railway seat allocation models have been developed, those models do not consider variables related to passengers' behavior. Owing to the facts that customers' demands are random and each customer's booking behavior is diverse, this study suggests that the seat allocation of a train should be dynamically adjusted during its reservation period according to its projected demands and the behavior of booking customers, especially their origins and destinations, amounts of demands, cancellation rates and retention rates. Therefore, this study proposes four dynamic seat allocation strategies and compares their performances using agent-based simulation models. This research incorporates the reservation records of 74,304 passengers from a railway company and extracts their booking behaviors from the data. During the reservation period, the demands of all travel sections and supplies of seats are estimated and optimized every day. In addition to maximizing revenues, the objective of minimizing the number of booking rejections to improve customer satisfaction is also evaluated. The results of this study show that our model has considerable improvement compared to the traditional static seat allocation method in all aspects, with revenue increases by 21% and customer booking success rate increases by 33%.

3 - Parallelization Techniques for Scheduling Algorithms in MATLAB and Python
Annika Tonnius

Due to the NP-hardness of many scheduling problems, heuristic and metaheuristic methods are commonly applied for these issues to find close-to-optimal solutions within an acceptable amount of time. However, for larger input data sizes faced in practice, even these approximation methods encounter their limits and require either highly performant hardware or a long computation time, which severely limits their scope of applicability. One way to compensate for the loss of efficiency is the implementation of parallelization techniques, i.e. processing multiple parts of an algorithm concurrently. The rising number of processing units in CPUs (Central Processing Units), as well as the availability of general-purpose interfaces for GPUs (Graphics Processing Units), emphasize the importance of parallelization in the future.

This work outlines the requirements necessary for the inclusion of concurrency in scheduling algorithms and the challenges related to the implementation of the technique in MATLAB and Python. Using the examples of the hybrid flow shop (HFS) and the classic traveling salesperson problem (TSP), the significant performance improvement of concurrent approaches is stressed by comparing highly parallelized algorithms to usual sequential implementations. It shows that even on commonly available hardware, parallel computing leads to a noticeable enhancement of the computation time. Eventually, the current limits of parallel computing are pointed out.

4 - A multi-objective transporting model of casualties to multiple medical centers in disaster response
Jie Deng

During a disaster response, there is a large number of injured people require medical aid at the same time, in order to save more lives, a traditional triage method is applied to determine the priority for receiving care for patients, since the transport and care resources are very limited in disaster situations, the transportation problem is how to effectively evacuate victims to the different area hospitals in order to provide the greatest good to the greatest number of patients while not overwhelming any single hospital, regarding the stochastic nature of casualty health, the spatial nature of multi-site emergencies and the dynamic capacity of hospitals, a model with the objectives with life-saving utility, delay cost, and fairness can formulate this problem, it is a set partitioning problem, and an algorithm with a column generation approach for Pareto-optimal policies is proposed, it is proved to solve the problem to near optimality within a short computation time, and the solutions derived by the algorithm outperform priority resource allocations.

■ TD-35

Tuesday, 14:30-16:00 - Q009

Evolutionary games, large-scale complex systems and applications

Stream: Game Theory and Mathematical Economics (contributed)
Contributed session
Chair: *Elena Gubar*
Chair: *Jonathan Burke*

1 - Nonlinear learning in evolutionary games with incompetence
Maria Kleshnina

The idea of incompetence as a learning or adaptation function was introduced in the context of evolutionary games as a fixed parameter. However, live organisms usually perform different nonlinear adaptation functions such as a power law or exponential fitness growth. Here, we examine how the functional form of the learning process may affect the social competition between different behavioural types. Further, we extend our results for the evolutionary games where fluctuations in the environment affect the behavioural adaptation of competing species and demonstrate importance of the starting level of incompetence for survival. Hence, we define a new concept of learning advantages that becomes crucial when environments are constantly changing and requiring rapid adaptation from species. This may lead to the evolutionarily weak phase when even evolutionary stable populations become vulnerable to invasions.

2 - Evolutionary dynamics for vaccination games
José Martins, Alberto Pinto

When vaccination is a voluntary option, the decision between to vaccinate or not is influenced by several aspects: the probability of being infected; the morbidity risks from the infection and also the morbidity risks from the vaccine, etc.. The decision of a single individual is also influenced by the decisions of the other individuals, because the course of the epidemics depends on that. In this work, we use evolutionary dynamic equations to study the evolution of the vaccination strategies and the evolution of the morbidity risks. Considering the reinfection SIRI model, we observe different vaccination scenarios for the same level of the morbidity risks.

Acknowledgements: The authors thank the financial support of LIAAD-INESC TEC and FCT - Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within project Dynamics, optimization and modelling", with reference PTDC/MAT-NAN/6890/2014.

3 - Generic Virtual Determinacy in Stationary Overlapping Generation
Jonathan Burke

For simplicity or realism, determinacy analysis for overlapping-generations models typically aggregate all conceivable commodities into a fixed, finite number of types. Analysis finds robust examples with indeterminate equilibria, which may suggest indeterminacy is essential to overlapping generations. But does robust indeterminacy exist despite simplifying aggregation? or because of aggregation? We prove the latter with a generic determinacy theorem for overlapping-generations models postulating idealized competitive markets for a continuum of commodities in discrete or continuous time. Indeed, aggregating the continuum of commodities into a fixed, finite number of types transforms some of those generic, determinate models into "robust" indeterminacy examples.

■ TD-36

Tuesday, 14:30-16:00 - Q010

Vehicle Routing with Time Windows

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Ana Paias*

1 - The vehicle routing problem with selective time windows depend on different demands
Yue Jiang, Chao Yang, Jun Yang

In this paper, we present a vehicle routing problem with selective time windows depend on different demands (VRP-STWD), which aims to determine the delivery strategy when each customer has one or more time windows but require to be served only one time. The cost of vehicles from a customer to another has different values in different time windows. The problem is formulated as a linear integer programming model which can be split in sub-models with various periods. A two-phase modified K-Means-Adaptive Large Neighborhood Search heuristic (MKM-ALNS) and a two-phase Tabu Search-modified Clarke and Wright Savings (TS-MCWS) heuristic are proposed to solve the problem. Finally, compared with the MIP solver of CPLEX and TS-MCWS over three sets of instances, MKM-ALNS can provide higher quality solutions to the problem.

2 - The PDP with alternative locations and overlapping time windows
Alina-Gabriela Dragomir, Tom van Woensel, Karl Doerner

Sending and receiving parcels can be a nuisance in both a B2C and C2C settings. Public post services or commercial shipping companies are not very accommodating for private mail by enforcing personal visits at pickup or drop off points, or simply by maintaining rigid schedules. Courier services on the other hand are often too expensive. None of these options are sufficiently accommodating. Therefore we propose the PDP with alternative locations and overlapping time windows. The transportation requests have to be served by a fleet of homogeneous capacitated vehicles, and each request may have multiple alternative pickup locations throughout the day with non-overlapping time windows (since the product cannot be in two places at once). Request may also have multiple alternative delivery locations, since the parcel is no longer delivered to a single specific person, but rather to a 'household'. A household consists of multiple persons in different locations that can be available simultaneously. Household members can accept the parcel at multiple locations throughout the day whether they are at work or at home.

We propose a solution approach combining a genetic algorithm and large neighbourhood search with problem specific operators to solve the pickup and delivery problem with alternative locations. Preliminary computational results are discussed and a comparison with already existing literature is provided.

3 - A Multi-Commodity Two-Echelon Capacitated Vehicle Routing Problem with Time Windows
Nico Dellaert, Tom van Woensel, Teodor Gabriel Crainic, Fardin Dashty Saridarq

An important city logistics solution approach for planning freight vehicles going into cities, each delivering small drop quantities, is to consolidate these volumes outside the city, in so-called urban distribution centers. In this case, a second layer of distribution centers is introduced, with the sole purpose to increase efficiency both stream upward (from the shipping warehouses) and stream downward (towards the customers). This paper studies the multi-commodity two-echelon capacitated vehicle routing problem with time windows. This problem takes customer-specific origin to destination, non-substitutable demands into account. The main components are: first echelon tours, second echelon tours and movement of commodities from first echelon to second echelon, considering route connection and synchronization. Exploiting the structure of the problem, we propose a decomposition scheme which decouples the first and second echelon routing problems, by deleting the third component, and re-couples them by using constraints ensuring movement of commodities between the two echelons. Based on this decomposition, we present a number of model formulations for the MC-2E-VRPTW, and develop an exact solution approach for this real-life problem. A computational study on a comprehensive set of instances shows the effectiveness in terms of computational effort and solution quality.

4 - A Matheuristic for a mTSP with Multiple Time Windows and Selective Cities: an application to Fishery Surveys
Ana Paias, Marta Mesquita

Fisheries surveys are fundamental to estimate abundances, recruitment and geographical distribution of fish species. Sampling operations are performed during working time hours at pre-defined locations. The research vessel visits each location once, according to one of a pre-defined set of time windows, and performs at most m circuits. Each circuit starts and ends at the home port and should not exceed a pre-defined number of days. Moreover, depending on its completion time, a visit to an intermediate port may occur, within the corresponding time window. This problem may be seen as variant of the multiple traveling salesman problem (mTSP) with multiple time windows and selective cities (the intermediate ports) aiming at optimizing the total traveled distance and the total completion time. We present a MILP model and propose a matheuristic that alternates between a genetic algorithm and a perturbation algorithm. The genetic algorithm provides feasible solutions by exploiting the routing subproblem related to the spacial movements of the research vessel defining the sequence of visits and the resulting set of circuits. The completion time is optimized by cost modifications given by a perturbation algorithm that uses information of the scheduling subproblem to guide the search of the genetic algorithm. Computational experience with real and benchmark based instances shows the effectiveness of the matheuristic.

■ TD-37

Tuesday, 14:30-16:00 - Q011

Dynamic and Stochastic Project Scheduling

Stream: Scheduling with Resource Constraints
Invited session
Chair: *Farzaneh Karami*
Chair: *Ugur Satic*

1 - Refining activity crashing hierarchy in complex projects through a data-driven simulation approach
Harish Rao

Uncertainty in project activity times increases the complexity in identifying the sequence of activity crashing in highly complex projects. In addition to the choice of the activity for crashing, the extent of crashing is also critical as it demands higher resource deployment.

We use a hypothetical complex project example where activities are closely interlinked with one another, resulting in many near-critical paths. Adding uncertainty to the activity durations and employing a simple simulation model, we identify the critical indices for each activity (probability of an activity being on a critical path).

As activity crashing is not a simple binary decision (crash or not to crash), we incorporate this uncertainty into the model by providing a hypothetical cost-time tradeoff function (linear assumption) for the activities.

We now compare the traditional deterministic approach with a simulation based approach in identifying the crashing hierarchy. The length of the simulation run is chosen suitably to give a rigorous and robust understanding of the uncertainties involved in the project. Employing criticality indices as parameters in the simulation based model aids the decision making process significantly.

Our simulation based approach offers a superior approach to addressing the problem at hand.

2 - Project Scheduling in Dynamic and Stochastic Resource Constrained Multi-Project Environments
Ugur Satic, Peter Jacko, Christopher Kirkbride

The goal of the Project Management is to organise project schedules to complete projects before their completion dates, specified in their contract. When a project is beyond its completion date, organisations may lose the rewards from project completion as well as their organisational prestige. Many uncertain factors such as random arrival of new projects and the uncertainty of task duration predictions may affect project schedules that lead to delivery overruns. This project scheduling problem in this environment is known as the dynamic and stochastic resource-constrained multi-project scheduling problem (DSRCMPSP). The motivation of this study is to create a comprehensive model which consider a system where projects (of multiple types) arrive at random to the resource-constrained environment for which rewards for project delivery are impacted by fees for late project completion and tasks may complete sooner or later than expected task duration. We model this problem as a discrete Markov decision process and use Dynamic Programming (DP) to determine a policy that maximises the average profit per unit time net of charges for late project completion. Capabilities of DP on the DSRCMPSP have been tested. The results are compared with a Genetic algorithm and a Priority Rule-based heuristic algorithm. The DP's results are up to 66% better than its closest alternative the Genetic algorithm for the scheduling problems with very tight due dates and high arrival rates.

3 - An Extended Robust Model for Project Time Analysis with Uncertain Data

Robert Hlavatý

The critical path method (CPM) has been a foundation of time analysis in project planning for decades. Assuming deterministic input data, one is able to determine the critical activities in a project as well as the minimum time needed to accomplish all activities. It is a common fact that the duration of activities is often hardly a precise value and estimations must be done instead. There are different means of dealing with uncertainty in project time analysis, such as PERT or GERT approach based on probabilistic evaluations according to a certain probability distribution and conditional probabilities. As an outcome of these methods, one can only expect results having a probabilistic character, too. In this contribution, we take an advantage of robust approach to deal with uncertainty in the time analysis. In this context, a project can be described as a network graph and consequently modelled as an integer programming problem. There are ways to implement the aspect of robustness into mathematical programmes but due to the nature of this particular problem, an ordinary approach is not suitable. Instead, we show how an extended robust programming model should be applied to project time analysis. This approach allows a decision maker to incorporate the aspect of uncertainty while keeping the model deterministic and enables to identify those activities with higher potential of criticalness.

4 - Scheduling with Resource Constraints (Economic Lot Scheduling Problem (ELSP))

Anders Segerstedt

The problem is to schedule the production of several different items consuming capacity on a single machine or production facility. The capacity is constrained but assumed sufficient to satisfy total demand; i.e. the demand that can be satisfied cannot exceed the capacity. The solution to the ELSP is order quantities and a realizable schedule without backorders and at the same time minimizing total costs. The problem is found in numerous practical applications: e.g. milling of gear houses, painting of metal rolls, paper production etc., both in process industries with more or less continuous flow and in workshops. It is often more economical to purchase one high-speed machine that is capable of producing many products than to purchase many dedicated machines. The ELSP-problem might seem simple to solve, but research has shown the problem to be complex, especially when considering both lot sizing and scheduling of capacity constrained facilities. Two factors contribute to the complexity of the problem: the need to satisfy the production capacity constraint and the need to have only one product in production at a time. These two factors along with the restriction that all demand must be met make the problem complex. NP-hard, in the strong sense. An overview of this problem is presented and its connection to the One-Warehouse N-retailer Problem and the Joint Replenishment Problem.

■ TD-38

Tuesday, 14:30-16:00 - Q012

Decision Aiding Methods 5

Stream: Multiple Criteria Decision Aid
Invited session
Chair: *Maria Barbati*

1 - Preference Learning and Interactive Multiple Criteria Decision Making

Srinivas Prasad, Atilla Ay, Shashidhar Kaparthi

We investigate the use of Preference Learning methods that are popular within the machine learning area in the context of Interactive Multiple Criteria Decision Making (MCDM). Interactive MCDM methods typically involve the design of preference elicitation strategies that attempt to use the available preference information to 1) identify what and how much additional information to elicit at a given stage, and 2) to minimize the overall information needed to either find partial or complete preference profiles. The elicitation strategy could depend on the need for how complete a profile is needed in a specific application. For example, in a group decision making context, partial preference profiles may suffice to generate a Pareto optimal set for the group. In this study, we examine how such preference elicitation strategies could be adapted for use within preference learning techniques that are used in machine learning.

2 - EMOSOR: Evolutionary Multiple Objective Optimization Guided by Interactive Stochastic Ordinal Regression

Michał Tomczyk, Milosz Kadzinski

We propose a family of algorithms, called EMOSOR, combining Evolutionary Multiple Objective Optimization with Stochastic Ordinal Regression. The proposed methods ask the Decision Maker (DM) to holistically compare, at regular intervals, a pair of solutions, and use the Monte Carlo simulation to construct a set of preference model instances compatible with such indirect information. The specific variants of EMOSOR are distinguished by the following three aspects. Firstly, they make use of two different preference models, i.e., either an additive value function or a Chebyshev function. Secondly, they aggregate the acceptability indices derived from the stochastic analysis in various ways, and use thus constructed indicators to sort the solutions obtained in each generation. Thirdly, they incorporate different active learning strategies for selecting pairs of solutions to be critically judged by the DM. The extensive computational experiments reveal that EMOSOR is able to bias an evolutionary search towards a part of the Pareto front being the most relevant to the DM. Moreover, we demonstrate that the performance of EMOSOR improves in case the forms of a preference model used by the method and the DM's value system align. Finally, we demonstrate that our novel questioning strategies allow to reduce a number of interactions with the DM until a high-quality solution is constructed.

3 - The Delphi method may improve decision-making processes in health care

Svetlana Daichman, Dan Greenberg, Oleg Pikovsky, Joseph Pliskin

A variety of new medical technologies makes the process of assessment and building up an optimal health portfolio rather challenging, especially while performed under budget constraints. The decision-making process of introduction of new technologies into the healthcare system is intended to diminish individual interests of policy makers and minimize possible biases and faults, while creating the best possible health portfolio. To be approved by different stakeholders, the priority-setting process must rely on quantitative and reliable methods of proven efficacy. However, significant limitations of traditional assessment methods do not allow optimal prioritizing of medical technologies; as a result, the portfolio may be far from representative and may not maximize the population's health. Our study suggests that the Delphi method may overcome the limitations of traditional methods for evaluation of medical technologies. The method can be used for reaching a rapid agreement on optimal utilization of healthcare system resources under budgetary constraints.

4 - A multiple criteria analytics integrated methodology for prioritizing and selecting urban cultural heritage projects for regeneration

Maria Barbati, José Rui Figueira, Salvatore Greco, Alessio Ishizaka, Simona Panaro

We present an integrated methodology supporting the choice of the reuse of urban cultural heritage. In particular, we deal with the prioritization and the selection of projects related to buildings of some values for the cultural heritage of the cities and it has been applied to the historical center of Naples, Italy. We evaluate each project on the basis of a set of both quantitative and qualitative criteria with the purpose to assess their level of priority for further selection. We perform this step through the application of the Electre Tri-nC method, allowing to assign a priority level to each project as an analytical recommendation tool. We define a set of resources (namely budgetary) and logical constraints that prevent the selection of the highest priority projects. Therefore, we build a portfolio selection model to find the efficient portfolios with respect to the levels of priority. The whole process has been conducted with municipality representatives and experts. The results of the interaction between analysts, municipality representatives, experts and decision maker representatives as well the complete methodological framework were well accepted for dealing with urban cultural heritage decisions. The proposed methodology is generic enough to be applied in other similar problems.

■ TD-39

Tuesday, 14:30-16:00 - Q014

Timetabling and scheduling in (public) transportation

Stream: Timetabling
Invited session
Chair: Greet Vanden Berghe

1 - A two-phase matheuristic for recovering bus driver rosters
Marta Mesquita, Margarida Moz, Ana Paias, Margarida Vaz Pato

In bus transit companies, the roster is a plan of work for a pool of drivers during a planning period of predefined length. This plan assigns a sequence of crew duties and days-off to each driver of the pool, complying with labour legislation and internal rules of the company. At real-time operational planning unexpected events may disrupt the roster leaving uncovered crew duties that should be re-assigned. Consequently, some drivers' previously assigned tasks should change or depot drivers (available to perform occasional service) may be called for driving work in the roster. We propose a matheuristic based on a MILP multicommodity flow assignment model that minimizes the number of depot drivers called for driving work, the dissimilarity between the recovered and the original roster and balances the workload. The matheuristic works in two phases by successively adding arcs to the multicommodity network aiming to increase the possibilities of recover and control the consequent computational requirements needed to restore the roster. In the first phase changes on previously assigned days-off are not allowed and depot drivers may be called for driving work. However, the company prefers to avoid the use of depot drivers. The second phase takes advantage of the first phase solution to locally replace depot drivers by drivers assigned to day-off and postponing their days-off. Computational experience derived from real data is presented and discussed.

2 - Vehicle Scheduling of Electric Buses using Column Generation
Nils-Hassan Quttineh, Carl Henrik Häll, Joakim Ekström, Torbjörn Larsson

In this talk we present a mathematical model for the Vehicle Scheduling Problems for Electric Buses (VSP-EB). The objective is to minimize the number of buses while satisfying constraints concerning routing and charging, including design choices of where to install charging equipment. This MIP-model formulation is not very strong, and already moderate size problem instances are challenging to solve to optimality.

A common approach to solve challenging vehicle scheduling problems is Column Generation (CG), and hence we explore the possibility of implementing an efficient column generation scheme for VSP-EB. Preliminary results are promising, improving best known solutions for some of our problem instances. Further, a modified CG method designed to accelerate the generation of columns is also presented, improving both solution times and best found integral solutions om a majority of the problem instances.

3 - Autonomous car experiment - predictable scheduling of computations
Zdenek Hanzalek, Joel Matejka, Premysl Sucha, Michal Sojka

Autonomous car applications require both high computational performance and predictable timing. Multi-core CPUs (we used NVIDIA Tegra X1 with four CPUs and one GPGPU) offer sufficient performance, but it is difficult to predict execution times because of cores competing for main memory. In this contribution, we present our self-driving car experiment with Porsche Panamera, and we explain main building blocks to be executed in real-time (object detection by camera and laser scanner, object tracking, data fusion, trajectory planning, longitudinal and lateral control). We achieve predictability on four CPUs by employing the predictable execution model, which splits execution into a sequence of memory and compute tasks, and schedules these such that only a single core is executing a memory task at a time. The memory task reads all the data required for the subsequent compute task in the CPU cache memory, and thus we avoid a cache-miss and related prolongation during the compute task. We formalize the problem as RCPSP/TW extended by a take-give resource (also called reservoir) used to represent the memory. We present a heuristic algorithm which is able to schedule the mid-size instances. For smaller instances, we compare the results of the algorithm with optimal solutions found by ILP. The results show that our approach maintains similar average performance to the original code and while reducing the variance of completion times.

4 - The Channel Scheduling Problem with Disjunctive Graph and Metaheuristics
Paul Corry, Christian Bierwirth

This work builds on a previous paper Corry and Bierwirth (2019) which introduced the Channel Scheduling Problem (ChSP) and integrated ChSP with the discrete Berth Allocation Problem (BAP). The problem considers a channel connecting an open sea anchorage with a set of berths for loading/unloading ships. A channel consists of a series of channel segments, which either allow or forbid passing of oncoming vessels. Following ships are permitted to concurrently occupy the same channel segment, but must observe a minimum separation time constraint on entry and exit to the segment. For a given set of berth allocations and berth sequences, the problem is to schedule movements of ships through the channel to minimise channel access delays at anchorage and prior to berth departure. The constructive heuristic (CH) proposed in the earlier study produces feasible, active schedules, of reasonable quality. This current study has hybridised this constructive heuristic with simulated annealing, by perturbing the order of insertion to the schedule. Desktop analysis found that the CH-hybrid could not reproduce all possible active schedules. Thus, the hybrid meta-heuristic searches a subset of active schedules, with no guarantee that the optimal schedule is contained within this subset. This insight has motivated exploration of other meta-heuristic implementations based on a disjunctive graph formulation of the problem.

■ TD-40

Tuesday, 14:30-16:00 - Q015

New Challenging Vehicle Routing Problems

Stream: Vehicle Routing and Logistics Optimization II
Invited session
Chair: Pieter Vansteenwegen

1 - The vehicle routing problem with cross-docking under cross-dock capacity restrictions
Emmanouil Zachariadis, Amalia Nikolopoulou, Panagiotis Repoussis, Christos Tarantilis

This work studies a new two-level vehicle routing problem with an intermediate cross-docking facility, capacity restrictions at the cross-dock and multiple operational constraints. The cross-docking practice has received research attention and several research works have been published considering routing decisions in distribution networks with cross-docking. A very common assumption in existing literature is that storage capacity at the cross-dock is unlimited. In practice however, this assumption is rarely true. The cross-dock capacity restriction has a direct impact on the scheduling of the cross-dock operations which in turn affects the timing of the outbound product flows, the customer time-window constraints, and thus, the overall network performance. In this work, we solve the vehicle routing problem with an intermediate cross-docking facility, temporal restrictions for customers, as well as capacity restrictions at the cross-dock. We consider the First-In, First-Out (FIFO) policy for the service of the inbound vehicles at the cross-dock. This is a common practice in real-world cross-docking distribution networks which, to the best of our knowledge, has not yet been addressed in the literature. To solve the problem, a local-search optimisation algorithm is developed. Computational experiments are performed to assess the effect of the cross-dock capacity on the vehicle routing costs.

2 - A Hybrid Solution Method for the Vehicle Routing Problem with Locker Boxes
Jasmin Grabenschweiger, Karl Doerner, Richard Hartl, Martin Savelsbergh

As a consequence of the online shopping trend, people tend to receive a lot of parcels nowadays. This brings new challenges for delivery companies. Customer convenience and logistic efficiency play a role when competitive strategies have to be found. To account for both aspects, we introduced the Vehicle Routing Problem with Locker Boxes. Customers can be serviced at their home address, but only within a certain time window. Apart from that, the parcels can also be brought to so called locker boxes, that are accessible 24/7 and close to the customer's home address or any other suitable place. The service aspect appears as a requirement on the minimum number of home deliveries. Efficiency of a routing plan is measured in terms of total travelled distance. A collaborative hybrid solution method is developed to solve the problem. In a first step Adaptive Large Neighborhood Search is used to solve the problem as a Vehicle Routing Problem with Time Windows, where the locker box stations are neglected. Then, some customers are taken out of the pure home delivery plan, and moved to locker boxes. At the locker box stations slots of different size are available and a bin-packing model is used to decide about the assignment of parcels to slots. The current capacity requirements of the locker boxes are returned to the routing algorithm and the resulting routing problem is re-solved in an iterative procedure. The algorithm is applied to real-world inspired instances.

3 - Optimizing routing and delivery patterns with multi-compartment vehicles
Markus Frank, Alexander Hübner, Manuel Ostermeier, Andreas Holzapfel, Heinrich Kuhn

This paper addresses a periodic vehicle routing problem for the determination of delivery frequencies using multi-compartment vehicles for grocery distribution. Efficient distribution planning is essential in grocery retailing due to low margins and a high impact of logistics costs on total retail costs. The store delivery policies and the resulting vehicle routes for replenishing store inventory from distribution centers reveal significant cost saving potentials. Retailers usually apply repetitive weekly delivery patterns when scheduling the workforce, defining cyclic transportation routes and managing warehouse capacities. In doing so, all logistics subsystems of a retail chain, i.e., warehousing, transportation and instore logistics, are jointly scheduled. Due to recent technological advances, retailers now have the option using multi-compartment vehicles. Grocery products requiring differing temperature zones (e.g. deep-frozen, fresh, ambient) can be transported jointly as the loading area is split into separate compartments. Packing the different product segments on one truck has also impact on the repetitive weekly delivery patterns. For example, instead of a separate delivery of frozen products once per week, the retailer can deliver this segment jointly with the daily deliveries of fresh products. After deriving decision-relevant costs, we propose a novel Periodic Multi-Compartment Vehicle Routing Problem to minimize total costs in all associated subsystems.

4 - A Metaheuristic for the Agile Earth Observation Satellite Scheduling with Time-Dependent Profits
Pieter Vansteenwegen, Guansheng Peng

The Agile Earth Observation Satellite (AEOS) is a new generation system equipped with imaging instruments who can rotate to observe targets. The objective is to maximize the observation profit when scheduling a subset of observation tasks during their time. The difficulty of this scheduling problem is threefold. Firstly, for each pair of consecutive observations, a transition time is required to maneuver the look angle of the imaging instrument. Since different observation start times have different look angles, the transition time depends on the observation start times. Secondly, the quality of an image, i.e. the profit of an observation, also depends on the observation start time. The maximal profit is collected at the middle of the time window. Lastly, each target has multiple time windows, but only one of them can be chosen for observation. We present a Bidirectional Dynamic Programming based Iterated Local Search (BDP-ILS) algorithm, equipped with an insert procedure avoiding a full feasibility check of the time-dependent transition time constraint. The BDP approach efficiently evaluates the solution and optimizes the observation start times. For benchmark instances without time-dependent profits, our algorithm performs on average 20% better than a state-of-the-art algorithm. When considering time-dependent profits, our algorithm performs very well on smaller instances with a known optimal solution and on larger instances compared to three reference algorithms.

■ TD-42
Tuesday, 14:30-16:00 - Q113

Transportation network vulnerability II

Stream: Transportation
Invited session
Chair: Leonardo Caggiani

1 - A multi-period model to minimize flood impacts on road infrastructures by planning mitigation measures: a case study in Hanoi, Vietnam
Siao-Leu Phouratsamay, Trung Hieu Tran, Maria Paola Scaparra

Hanoi city, in Vietnam, is the fourth highest city in the world exposed to floods. During extreme rainfall events, flooding occurs due to the aged drainage system, causing serious economic impacts. A social and economic impact assessment carried out in Hanoi during July 2018 showed that the most important flooding impact concerns the road infrastructures. A few studies in the literature have addressed the problem of mitigating flood to minimize the impacts on road infrastructures. In our work, we consider the implementation of mitigation measures to improve the drainage system of Hanoi, including the construction of manhole and the rehabilitations of lakes. The mitigation measures can be implemented independently over a discrete time horizon. We present an optimization problem to determine an optimal planning with two objectives: minimizing the damages on road infrastructures and minimizing the congestion level. We assume that a limited budget is available in each time period to implement the mitigation measures. The problem is formulated as a mixed-integer nonlinear programming model and solved by a Greedy Randomized Adaptive Search Procedure (GRASP) heuristic to deal with the non-linearity of the objective function. The heuristic is integrated in a decision support system and is tested on a case study in Hanoi city.

2 - Uncovering community structure in a citation network of vulnerability studies in transportation and complex networks
Kashin Sugishita, Yasuo Asakura

For about 20 years, studies on network vulnerability have been grown rapidly in two fields of transportation and complex networks. Even though research topics in both fields are similar, mutual understanding and interdisciplinary studies are currently limited. In this study, toward further development of both academic fields, a citation network consisting of the vulnerability studies in the aforementioned fields is analyzed. Firstly, the publication records related to network vulnerability are obtained from an online academic data base, Web of Science. Secondly, a citation network, where each node represents a publication and each directed link represents a citation relation from the citing article to the cited article, is constructed. The constructed citation network has 1,181 nodes and 4,601 links. Thirdly, the giant weakly connected component (GWCC) is extracted from the constructed network. The extracted GWCC has 705 nodes and 4,584 links. Fourthly, an overlapping community detection algorithm is performed in order to reveal the overall structures of the vulnerability studies. This study aims to contribute to understand the current entire pictures of the vulnerability studies and to encourage more active interdisciplinary studies in the future.

3 - Effectiveness of resilience indicators of public transport networks. Analysis of the application to six bus benchmark networks

Neila Bhouri

In the current urban environment, the study of system resilience is of increasing interest, not only because of major events, traffic disruptions, climatic incidents, or terrorism attacks, but also because of the network complexity and its near-saturation. An incident, even a very small one, can have unfortunate consequences and impacts on a large part of the network. In this context, it is essential to have an operating tool that adapts to changes due to performance degradation with minimal loss of network functionality.

One of the challenging engineering problems is the design and development of a resilient system for public transport operation. To achieve this objective, we studied the most known resiliency indicators from the topology and flow point of views. Robustness, Physical Reliability, Recovery, Managing Index, Adaptability, etc. all these indicators are tested on benchmark networks. The paper will dress methodology applied to six bus public transport networks of Swiss road network initially reported by Mandl on 1980. These six selected bus network have the same transit stop locations, passenger travel demand, and travel time matrices; having different passenger flow distribution and connectivity pattern. A method to evaluate the magnitude of disruption and assessment of indicators on these six networks will be presented. Results include the indicators values for each transit network, impact analysis of disruption scenarios and discussions

4 - An Equity-Based Model for Bike-Sharing Stations Location in Multimodal Bicycle-Transit Transport

Leonardo Caggiani, Michele Ottomanelli

A suitable multimodal transport network design can reduce the problems related to traffic congestion and push users to use sustainable public transport systems. However, implementing new infrastructures and/or transport systems on an existing network may generate social disparities which negatively affecting some individuals (especially those with a low income) more than others. For these reasons, it is necessary to study the relationship between transport costs and social equity, aiming at understanding the effects of the design on both accessibility to the transport system and on different groups living in the studied area. In this paper, we propose an equity-based model for bike-sharing stations location considering bicycle-transit multimodal trips. We first propose the definition of a new equity indicator, based on bicycle-transit accessibility value in an urban context. Then, through this indicator, it is possible to define, for each social class of users, a different level of bicycle-transit accessibility. The proposed optimization model aims at maximizing the value of equity, based on the proposed indicator, considering the given transit network and designing the positions of bike-sharing system stations on the network. Such a designed bike-sharing system can promote social inclusion and the use of bicycle as a sustainable transport mode for first and last mile connections. The suggested model has been applied to a test network obtaining promising results.

■ TD-43

Tuesday, 14:30-16:00 - Q114

Competitive Location in retail

Stream: Location Analysis and Optimization
Invited session
Chair: *Vladimir Marianov*

1 - Heuristic Algorithm for Asymmetric Competitive Facility Location

Algirdas Lančinskas, Pascual Fernandez, Blas Pelegrin, Julius Žilinskas

Competitive facility location is important for firms which provide goods or services to customers and compete for the market share with other firms in a certain geographical area. There are various facility location models and strategies to solve them, which vary on their ingredients such as facility attraction function, customers behavior rules, decision variables, search space, objective functions, etc. A lot of facility location problems use a symmetric objective function that is unchanged by any permutation of its variables. However, real-world applications usually make us deal with asymmetric facility location problems, where the position of a facility in the solution is crucial. We address the asymmetric discrete competitive facility location problem for an entering firm and propose a heuristic optimization algorithm based on the ranking of candidate locations to solve the problem. The proposed algorithm is specially adapted for discrete facility location problems by utilizing their features such as geographical distances, quality of facilities, etc. Performance of the algorithm is experimentally investigated by solving different instances of the competitive facility location problem with asymmetric objective function. This research is funded by the European Social Fund under the No 09.3.3-LMT- K-712 „Development of Competences of Scientists, other Researchers and Students through Practical Research Activities" measure.

2 - Using GeoMarketing criteria for Retail Site Location Selection Problem: Case of a Sports-Goods Retailer in Turkey

Ozay Ozaydin, Yeliz Cotoy

Companies face site location selection as a critical problem due to its nature. It's a decision that is hard to imitate and have the potential to create a significant competitive advantage. Companies run analyses to support and develop marketing activities. Combining geographic and demographic data to analyze and to create actionable marketing insights is called GeoMarketing. The effects of using GeoMarketing criteria for location selection problem is analyzed in this study. A decision model is developed for determining the most suitable areas for opening multiple retail stores in various capacities throughout Turkey. AHP weighted TOPSIS and VIKOR methods are used to determine the results.

3 - The follower competitive location problem with comparison-shopping

Vladimir Marianov, H.a. Eiselt, Armin Lüer-Villagra

We address the competitive location problem, in which firms locate their stores to take advantage of consumers' behavior to maximize their market share. So far, competitive location-prescribing models have addressed a situation in which a consumer goes to a chosen store, makes a purchase and comes back to her origin point. A common and more complex behavior is comparison-shopping; by which consumers visit stores belonging to different retail chains selling mutually imperfect substitute products, before deciding whether making a purchase, and where. In our case, two chains or firms, leader and follower, each selling one product or brand of products, locate their stores sequentially, and consumers decide their trips once the stores are located. Given existing branches of the leader firm, we address the location problem for a follower firm that locates its own branches. We propose the necessary utility functions that represent the comparison-shopping behavior, present insights on the instance used by ReVelle in his maximum capture formulation, and computational experience with one thousand 100-node instances. The results are compared in terms of the demand captured by each firm and the locational patterns that result from different consumer behaviors.

4 - Bilevel programming models for multi-product location problems
Sebastián Dávila, Martine Labbé, Vladimir Marianov, Fernando Ordonez, Frédéric Semet

We consider a retail firm that owns several malls with a known location. A particular product, e.g., food processor, comes in p types, which differ by shapes, brands and features. Each mall has a limited capacity of products to be sold at that location, so the firm has to choose what products to sold at what mall. Furthermore, the firm can apply discrete levels of discount on the productsover the price of product. The objective of the firm is to find what products to sell at which mall, with what level of discount, so that its profit is maximized. Consumers are located in points of the region. Each consumer or group of consumers has a different set of acceptable products, and will purchase one of these, or none if it is not convenient for her. Consumers maximize their utility, i.e., the surplus obtained substracting the full cost of the product from the reservation price.

The agents (firm and consumers) play a Stackelberg game, in which the firm is the leader and the customers the follower. Once the firm decides the products to sell at each mall and the possible discounts, consumers purchase (or not) one of their acceptable products wherever their utility is maximized. We model the problem using first a bilevel formulation, and we further replace the follower problem by the primal constraints and optimality restrictions, to obtain a compact formulation.

■ TD-44

Tuesday, 14:30-16:00 - Q115

AHP Application

Stream: Analytic Hierarchy Process
Invited session
Chair: Erdem Aksakal

1 - Ranking of Seismic Retrofit Strategies for Industrial Buildings: A Hierarchical Approach
Francesca Andreolli, Chiara D'Alpaos, Flora Faleschini

Recent destructive earthquakes in Northern and Central Italy significantly damaged residential and industrial buildings and historic centers. Earthquakes occurred in 2012 in Emilia-Romagna seriously affected the economy of this area due to the collapse of a large number of industrial buildings: estimated direct and indirect economic costs were about 6 billion Euros. In this context, the management of post-earthquake recovery operations and the adoption of preventive seismic risk mitigation strategies is of paramount importance. Effective strategies require the stabilization of severely damaged buildings and the preventive improvement of constructions structural response to seismic actions. Although emergency inspections are meant to classify buildings based on building residual seismic capacity, decisions on prioritization of interventions depend on different criteria related to both buildings structural characteristics and materials, and to peculiarities of manufacturing and production of goods and services supplied. In this paper, we investigate different seismic retrofit strategies and we propose an AHP model for multicriteria prioritization of post-earthquake intervention on industrial buildings. We take into account multiple criteria grouped into technical (e.g. vulnerability, compatibility, reversibility), economic (e.g. construction costs, costs due to production downtime and disruption of occupancy) and social (e.g. social reputation, workers' wellbeing) criteria.

2 - Application of hybrid A'WOT method to European electricity interconnections planning
Giulia Crespi, Cristina Becchio, Ettore Bompard, Marta Bottero, Stefano Corgnati, Zhengyi Han, Tao Huang

Aiming to achieve a clean energy transition, European electricity system is experiencing a strong transformation, to better integrate higher variable renewables. This will increase the needs and chances for cross-border electricity exchange, asking for a higher globally interconnected system. Tackling such transition from a pure technical perspective is limiting, since energy systems are enclosed in complex economic, social and political patterns, and thus the necessity of meeting different criteria at once (social, economic, political, environmental, technical) is a demanding task for energy policy makers. As a support to decision-making, the hybrid A'WOT method is applied in the context of EU grid interconnection with surrounding areas (Africa, Greenland, Russia, Eurasia, China). A'WOT approach couples SWOT and multi-criteria analyses (in the form of Analytic Hierarchy Process, AHP) to benefit from both. SWOT is suitable for depicting strengths, weaknesses, opportunities and threats of the decision-making process and for selecting the appropriate criteria, while AHP is particularly useful for helping decision makers to achieve reasonably consistent preferences. In detail, five models were developed, each studying the EU interconnection with one of the aforementioned areas. By integrating multiple criteria influencing the decision-making process, the A'WOT was used per each model to define the countries more suitable for hosting the future electricity interconnections.

3 - Hybrid Use of AHP and IRP Methods for Ski Destination Selection: A Case for Turkey
Erdem Aksakal, Tubanur Erzincanlı

In recent years, sport tourism has become much more popular. Because sport is an important activity within the group of tourism activities. This popularity formed the sport tourism to be more important in economic sense. Due to being popular and having economic importance, service providers have begun to consider more attention on sport tourism. But the concept of sport tourism is complex because of the characteristics between the customers is quite a change. This situation limited the growth and quality of the service. As a subcomponent of sport tourism, winter sports (especially ski) tourism becomes one of the important and key economic factors in many regions worldwide. Having a unique location according to its geographical position, Turkey stands like a natural bridge between Asia and Europe. With respect to location, Turkey becomes one of the favorite winter tourism destinations. The purpose of our study is to give a brief overview of the profile of ski destinations in Turkey by the examination of the status of the destinations through a case study. In the study, integrated Analytic Hierarchical Process (AHP) and Interpreter Sorting Process (IRP) method used as hybrid. 8 criteria and 6 alternative determined for to find the best alternative The weights of criteria computed by AHP then IRP applied to rank the alternatives.

■ TD-45

Tuesday, 14:30-16:00 - Q117

Green Maritime Logistics

Stream: Green Logistics
Invited session
Chair: Dario Pacino

1 - A Genetic Algorithm for Finding Realistic Sea Routes Considering the Weather
Stefan Kuhlemann, Kevin Tierney

The weather has a major impact on the profitability, safety, and environmental sustainability of the routes sailed by seagoing vessels. The prevailing weather strongly influences the course of routes, affecting not only the safety of the crew, but also the fuel consumption and therefore the emissions of the vessel. Effective decision support is required to plan the route and the speed of the vessel considering the forecasted weather. We implement a genetic algorithm to minimize the bunker consumption of a vessel taking into account the two most important influences of weather on a ship: the wind and the waves. Our approach assists route planners in finding cost minimal routes that consider the weather, avoid specified areas, and meet arrival time constraints. Furthermore, the algorithm generates routes avoiding sharp changes in direction to ensure they can be sailed by even large vessels. The algorithm is evaluated in a variety of scenarios to show the impact of weather routing on the routes and the fuel and travel time savings that can be achieved with our approach. Including weather into the routing leads to a savings potential of over 10 % of the fuel consumption. Furthermore, we show that ignoring the weather when constructing routes can lead to routes that cannot be sailed in practice.

2 - Solving the pre-marshalling problem with real crane time minimization objective
Consuelo Parreño Torres, Rubén Ruiz, Ramon Alvarez-Valdes, Kevin Tierney

Port efficiency is determined by several parameters, among which berthing times of ships stands out. The correct arrangement of the container yard prior to the arrival of ships dramatically reduces such times and therefore increases the efficiency and the competitiveness of the terminals. The pre-marshalling problem (CPMP) seeks to transform the initial layout of a bay into a final layout without blocking containers. So far, the number of required movements has been used as an indicator of the time employed by the crane to rearrange the bay. Nevertheless, this paper shows that this indicator is not entirely representative. Therefore, we study a variant of the CPMP whose goal is to minimize the actual time spent by the crane to rearrange the bay (CPMPCC), thus reducing energy consumption. We propose integer programming models as well as a metaheuristic approach. An extended computational analysis is carried out over well-known pre-marshalling datasets, testing both exact models and the heuristic approach.

3 - Service independent liner shipping vessel routing
Daniel Wetzel, Kevin Tierney

Liner shipping networks are a central feature of modern supply chains consisting of cyclical, periodic services that are operated by ships. While the specialized structure eases planning for both shipper and carrier, the available time windows at ports can lead to inefficient sailings within a service. Excluding these inefficient port visits reduces the costs of a service network. We propose to change the way ships sail on the predefined schedules, allowing them to move between services to avoid inefficient connections. From the view of a shipper, the cyclical and periodic properties of the services still hold, and the liner carrier can offer a more efficient overall network. The resulting optimization problem consists of a cargo allocation problem (i.e., container routing) as well as a vessel routing problem, resulting in large and difficult instances. We use a mixed-integer linear programming model to model this problem and investigate methods for efficiently finding solutions and compare them to their standard cyclical schedule equivalents.

4 - A column generation procedure for the Flexible Ship Loading Problem
Jonas Christensen, Dario Pacino

In search of economies of scale container shipping lines are building bigger and bigger vessels. Over the last decade the average capacity of container ships has doubled, and as of May 2017, OOCL Hong Kong holds the world record for the largest containership, with a carrying capacity at 21,413 TEU. That is a factor 2.6 increase compared with the 8,200 TEU record set in 2003. It is expected that the size of containerships will grow over the coming years.

Bigger vessels require more crane moves per vessel, and terminals are under pressure to minimise the turnaround time for the vessels. Minimizing the turnaround time makes it possible for the carriers to realise more of the savings potential that comes with the bigger vessels, as they will not have to catch-up on the sea to stay on schedule because of port delays.

The Flexible Ship Loading Problem (FSLP), investigates a problem aimed at improving terminal productivity. In the FSLP it is assumed that the liner and the port enters a data sharing agreement to the benefit of both. We assume that the liner provides the terminal with a stowage plan based on container classes. The terminal then has the responsibility of making the final operational stowage plan. Doing so, the terminal can better plan the use of their resources and improve terminal productivity. In this talk, we wish to present a column generation based method to solve the Flexible Ship Loading problem. The results will be compared to a compact MIP formulation.

■ TD-46

Tuesday, 14:30-16:00 - L243

Advances in Variational Inequalities and Equilibrium Problems II

Stream: Variational analysis, games and intertwined optimization problems
Invited session
Chair: Laura Rosa Maria Scrimali

1 - Inverse fixed point iteration and applications to equilibria
Maria Carmela Ceparano, Francesco Caruso, Jacqueline Morgan

We first address the issue of the existence of a unique fixed point for a class of strongly monotone operators defined on a Hilbert space, extending the results obtained for Nash Equilibria in Caruso, Ceparano, Morgan (2018, J. Math. Anal. Appl.). Then, by using an inverse iteration scheme, we investigate a method for the approximation of the unique fixed point of the operator and we present applications in game theory and quasivariational analysis frameworks.

2 - A variational formulation of financial networks
Patrizia Daniele, Sofia Giuffre', Antonino Maugeri

We present a general financial equilibrium problem related to individual entities, called sectors, which invest in financial instruments as assets and as liabilities. A variational inequality formulation and an existence result are provided. Also, we study the dual Lagrange problem, in which the Lagrange variables, which represent the deficit and the surplus per unit, appear. By means of such variables, we may study the insolvencies associated with the financial instruments and their propagation to the entire system, producing a "financial contagion". As expected, the presence of the insolvencies makes it more difficult to reach the financial equilibrium and increases the risk of a negative contagion for the all system.

3 - A globally convergent strengthening of the Newton-min algorithm nonlinear complementarity problems
Jean-Pierre Dussault, Mathieu Frappier, Jean Charles Gilbert

The semismooth Newton method is a very efficient approach for computing a zero of a large class of nonsmooth functions. When the current iterate is sufficiently close to a solution and the function is strongly semis- mooth, the method converges to the zero quadratically. Otherwise, it is dif- ficult to force the convergence using linesearch or trust regions because a semismooth Newton direction is not necessarily a descent direction of the associated least-square function, unlike when the function is differentiable. We explore this question in the particular case of a nonsmooth equational formulation of the nonlinear complementarity problem using the min func- tion. We propose a globally convergent algorithm using a modification of the semismooth Newton direction that makes it a descent direction of the least-square function at any point. Next, we present heuristics to improve its efficiency while maintaining the local finite termination of the algorithm in a neighborhood of a solution when the function is linear. An intensive numerical exploration of a careful implementation of the proposed method shows that it is competitive on some applications and on randomly generated problems, which we view as an indication saying that the approach deserves more investigations.

■ TD-47

Tuesday, 14:30-16:00 - L247

Heuristic and Evolutionary Algorithms for Continuous and Black-Box Optimization: theory and practice

Stream: Continuous and Black Box Optimization
Invited session
Chair: *Angel A. Juan*
Chair: *James McDermott*

1 - Program Trace Optimisation for the Travelling Tournament Problem
James McDermott

The Travelling Tournament Problem (TTP) is a combinatorial optimisation problem where the goal is to produce a schedule for a sequence of home-away fixture pairings in a sporting competition, such as a football league. It has previously been approached using both classical optimisation and metaheuristic optimisation methods.

Program Trace Optimisation (PTO) is a recent optimisation algorithm which aims to make the user's job much easier. In contrast to typical metaheuristics, where the user must design a representation consisting of data structures and search operators, in PTO the user must to create a non-deterministic generator function (together with the usual objective function). The generator function takes no arguments and returns one solution sampled from the search space. PTO internally traces the execution of this function, recording the sequence of choices made at non-deterministic points in it. This "program trace" becomes the highly general underlying representation. We say that PTO *automatically and implicitly* designs good problem-specific operators.

Any search method can be "plugged-in" to PTO and in this paper we use late-acceptance hill-climbing.

In this paper we compare PTO generators for the TTP.

2 - Using Biased-Randomization for solving a Non-Smooth Facility Location Problem with Soft Constraints
Angel A. Juan, Alejandro Estrada-Moreno, Albert Ferrer, Adil Bagirov, Javier Panadero

We discuss the facility location problem with soft capacity constraints. Hence, the maximum capacity at each facility can be potentially exceed by incurring in a penalty cost, which increases with the constraint-violation gap. In some realistic scenarios, this penalty cost can be modeled as a piecewise (discontinuous) function. As a result, the traditional cost-minimization objective becomes a non-smooth function that is difficult to optimize using exact methods. A mathematical model of this non-smooth optimization problem is proposed, and a biased-randomized iterated local search metaheuristic is introduced as a solving method. A set of computational experiments is run to illustrate our algorithm and test its efficiency.

3 - A Learnheuristic approach for the mobile transceiver facility location problem
Christopher Bayliss, Angel A. Juan, James McDermott

This work proposes a learnheuristic approach to solve the mobile antenna facility location problem. The goal is to minimize the total antenna deployment and service costs such that all demands are covered. The mobile antenna facility location problem has a number of complicating constraints. Mobile transceivers have a limited capacity for transmitting data, signal quality depends on the terrain and weather conditions, booster transceivers can be deployed in high demand areas, transceiver have a number operating modes which effect the coverage area and demands may fluctuate over time. The problem is formulated as a mixed integer linear program (MIP). However due to the complexity and scale of the problem using a commercial solver is intractable. This work proposes a learnheuristic approach in which the integer variables are solved by a metaheuristic algorithm which solves the remaining real variables via a linear program. Within the learnheuristic algorithm the linear programming solver plays the role of the black-box reality module and the metaheuristic algorithm plays the role of the optimization module. Due to the scale of the problem the black-box is a bottle neck on the algorithm. Learnheuristics employ machine learning algorithms to approximate the black-box during the runtime of the algorithm. For this task a neural network is used. In experiments this work shows that the learnheuristic is able to generate high quality solutions quickly compared to several alternatives.

4 - A Biased Randomized Algorithm applied to Asset Liability Management
Armando Nieto, Angel A. Juan

Most of the insurers and a wide part of private banking have to deal with liabilities extended in the long term. This translates in the necessity of choosing the appropriate assets to match with the debts. In this work, we show an effective biased randomized algorithm that leads to a selection of our asset portfolio subject to conditions. This algorithm is easily customizable to search any required goal such as duration, best cash flow fit, or less expensive portfolio, following the different approaches that are described in the financial literature.

■ TD-48

Tuesday, 14:30-16:00 - L248

Energy Systems

Stream: Applications of Dynamical Models
Invited session
Chair: *Mette Gamst*

1 - Optimally allocating a chain of charging stations for electric vehicles along a highway
Alexander Belenky, Alain Kornhauser

Charging stations along highways crossing geographic regions form one of the two major parts of the charging infrastructure for electric vehicles, and an approach to optimally allocating a chain of these stations along a highway is proposed. Proceeding from a) an expected (but unknown exactly) electricity demand at each charging station from the chain, b) the available types of and the market prices for the equipment that can be installed at each charging station, c) both legal and technological constraints affecting the distance between the stations in the chain, and d) the maintenance and operational costs associated with each charging station from the chain, an estimate of the investment volume needed for developing the chain is found by solving a large-scale optimization problem with a linear structure of constraints and mixed variables. That is, a problem of maximizing the minimum function of a sum of two bilinear and several linear functions of vector arguments is solved. A reduction of solving this problem to solving either a mixed programming problem or an integer programming problem and a linear programming one is proven. The mathematical model underlying the formalization of the allocation problem allows one to consider that both the existing electrical grids and alternative sources of energy such as solar panels and wind turbines may supply the charging stations from the chain with electricity either directly or via various electricity storing systems.

2 - Time aggregation techniques applied to integrated energy systems
Mette Gamst, Stefanie Buchholz, David Pisinger

Simulating energy systems is vital for energy planning. The green transition continues to introduce fluctuating renewable energy sources and integration of different types of energy. Simulating energy systems is necessary to understand system behavior and the effects of investing in new technologies. In this context, an energy system simulation consists of a year in one hour resolution, i.e. of 8760 hours. Also, an energy system may consist of many geographical areas (e.g. electricity bidding zones) and energy types (e.g. electricity, district heating, gas). For this reason, simulations may become very time consuming and even intractable. The literature suggests a wide variety of aggregation techniques, which are all focused on reducing the number of time steps needed to represent a full year. The far majority of the literature, however, considers simple energy systems consisting of just a single electricity bidding zone. We have implemented selected aggregation techniques on full scale, real life energy systems with multiple geographical areas and energy types. In this presentation, we analyze the implementations and the results. By implementing the aggregation techniques on very different types of energy systems, we aim to provide general insights on gains and drawbacks of the techniques.

3 - Impacts of pipeline network reform on the primary distribution system of oil products in China: energy, economy and environment
Meng Yuan, Yongtu Liang

State-owned monopolies on pipelines lead to low energy efficiency, expensive logistics costs and high GHG emissions in the primary distribution system of oil products (PDO) in China. With the pressures on energy demand and emission mitigation, the reform on the pipeline network is imperative. However, the selection of appropriate reform policy is controversial, and no researcher has conducted quantitative analysis on this issue. In this paper, we establish an integrated framework to provide scientific decision-support for evaluating the impacts of pipeline network reforms on the PDO system in China through coupling the mathematical programming technique and the energy-economy-environment (3E) assessment method. Five scenarios are designed including the baseline (BAU) and four types of reform policies, namely third-party access (TPA), pipeline network integration (PNI), business cooperation (BC) and third-party access combined with business cooperation (TPA-BC). Based on the analysis results, it can be concluded that (i) all reform schemes have significant benefits in 3E aspects; (ii) the order according to 3E performance presents as follows: TPA-BC> BC> PNI> TPA> BAU, and (iii) only when the pipeline networks need to reserve high capacity margin, the advantages of PNI compared to TPA could be revealed, and otherwise the gap between them is small.

■ TD-49

Tuesday, 14:30-16:00 - L249

Software for large-scale optimization II

Stream: Software for Optimization
Invited session
Chair: Yuji Shinano

1 - Overview of Decision Optimization for Watson Studio
Sofiane Oussedik

This presentation will give you an overview of IBM Decision Optimization for Watson Studio, a data science platform with decision optimization and machine learning capabilities, it allows data scientists to build and evaluate machine learning and optimization models in a unified environment.

Business analysts can configure and evaluate proof-of-concept applications based on the data scientist's models, then application developers can integrate the artifacts created into the operational application required by the line-of-business stakeholders.

2 - The primal-dual integral for nonlinear problems
Zsolt Csizmadia, Timo Berthold

We extend the concept of the primal-dual integral introduced by Berthold for mixed integer problems to nonlinear and mixed integer nonlinear problems with an emphasis to enable its application to both global, and local solvers or heuristics that do not provide valid bounds to the optimal objective. We discuss interpretation on both public and industrial test sets.

3 - Efficient computation of derivatives for solving optimization problems in R and Python using SWIG-generated interfaces to ADOL-C
Sri Hari Krishna Narayanan, Julie Bessac, Paul Hovland, Kshitij Kulshreshtha, Kaitlyn MacIntyre

Scripting languages are gaining acceptance because of their ease of use and value for rapid prototyping in many fields, including machine learning and statistics. In the context of algorithmic differentiation (AD), however, the main development effort continues to be concentrated on traditional compiled languages such as Fortran and C/C++. There is therefore a need for AD tools for computing derivatives efficiently within scripting languages. ADOL-C is an operator overloading-based C++ library that provides accurate first- and higher-order derivatives for applications in C++. SWIG is a preprocessor that uses the C/C++ header files to wrap the API of a library to be callable from scripting languages such as R and Python and several other high-level programming languages. The overall process of making the C/C++ API available via SWIG is largely the same for all scripting languages. After an initial effort required per language, only minimal effort is required to maintain the scripting interface in sync with upstream developments in the original C/C++ library. In addition to achieving our original goal of creating an interface for R, we were able to generate an interface for Python that proved an order of magnitude faster than the previously implemented interface. This talk gives an overview of the interface generation process, the challenges we encountered with both scripting languages, and some numerical results to demonstrate both usefulness and efficiency.

4 - Configuring ParaXpress to Enhance its Heuristic Performance
Yuji Shinano, Timo Berthold, Lluis-Miquel Munguia

ParaXpress is a distributed memory parallel MIP solver based on the FICO Xpress-Optimizer and the Ubiquity Generator (UG) Framework. ParaXpress so far has been tuned to prove optimality quickly. In this talk, we want to investigate how a distributed memory MIP solver can be best utilized for finding high-quality feasible solutions quickly. To this effect, we present UGS, another software framework which allows to run different solvers to solve a single instance exchanging incumbent solutions. In addition to fully-fledged MIP solvers, UGS enables the use of PACS-X, a parallel implementation of the Alternating Criteria Search heuristic based on Xpress. With UGS, we combine different configurations of ParaXpress with PACS-X and present computational results for the configuration selection.

■ TD-50

Tuesday, 14:30-16:00 - Mason Hayes & Curran

Different perspectives on Problem Structuring Methods

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: Isabella Lami

1 - Projecting decisions. The architectural design practice in the folds of decision-making processes
Elena Todella

The decision-making processes of complex urban and architectural transformations - dependent on several implications and actors - have a high degree of uncertainty and wickedness, in the process itself and in the outcomes. However, in architectural field, this kind of complexity is often accounted as a linear process of subsequent steps and decisions, from the cause to the effect, from the project to its execution. Since projects rarely move forward - without detours - to buildings, how is it possible to take account of their diversions as constituent elements of the decision-making process? In order to witness the folds of architectural design, I shift the attention from the products of architecture - as buildings - to the processes of project conception and negotiation, by following the practice in a pragmatic way. In this, Problem Structuring Methods (PSMs) offer an approach to investigate what occurs in the micro-processes of conflicts, negotiations and social interactions between multiple individuals and entities. Then, this work is an attempt to apply some PSMs' paradigms and categorizations to architectural design practice, in order to unfold and trace the entities involved, their role and their interactions and to link them to the effects in the decision-making process. The case study is a multi-sited and large-scale process, since I was involved - over two years - in the Project Team of the Masterplan of the Politecnico di Torino's urban campuses.

2 - MULTI-METHODOLOGY AND URBAN RENEWAL: Strategic Choice Approach and SRF for dealing a territorial conflict
Francesca Abastante, Isabella Lami

The research proposes a multi-methodology approach for tackling a conflicting territorial decision problem, related to an ongoing research. There are several ways in which combinations of different methodologies, or part of it, can occur within a single intervention, each having different problems and possibilities. In particular, the multi-methodology here proposed is a combination of the first three phases of Strategic Choice Approach (SCA)- the shaping mode; the designing mode and the comparing mode- with a Multicriteria Decision Analysis, the Playing Cards called Simos-Roy-Figueira (SRF), applied in the third step for selecting the comparison areas. The proposed assessment framework is here applied to the identification of possible alternative strategies for Chiomonte (Italy). It is a small town located in the Susa Valley, which is the core of a huge territorial conflict, because it has been identified as the main Italian working site for the High Speed Train (HST) line from Turin (Italy) to Lyon (France). This territorial conflict can be interpreted in several ways: as the consequence of the imbalance between concentrated costs and distributed benefits; as the resistance of the places against the flows that invade or cross them; as a demand for a different model of development. In this conflicting situation, inevitably highly complex and multi-dimensional, multimethodology could contribute to deal effectively with the full richness of the real world.

3 - Value-Focused Thinking versus Alternative-Focus Thinking approach. How to support design process by values
Marta DellOvo, Alessandra Oppio

The design of quality alternatives is still considered as a crucial issue in many decision-making contexts. When the problem consists of creating different options for sustainable urban development, the decision is even more critical since there are several needs, values and objectives to be investigated in order to identify the most satisfactory alternative from among those available. Addressing decisions to the good enough solution rather than to the optimal one depends on many reasons, such as: the difficulty to access and process the information needed to take a good decision; the instance of achieving a balance among different dimensions of urban development, namely the economic, environmental and social ones; the not always consensual preferences of the stakeholders involved in these kind of processes. Starting from these premises, what deserves to be explored and represents a major challenge in the context of design is the modeling phase, when objectives are identified and alternative strategies and actions are defined. In order to provide a contribution to the empirical line of research on alternative generation, the paper compares within a design process the Value-Focused Thinking approach, based on values' elicitation, in contrast to the Alternative-Focused Thinking (AFT), based on the generation of alternatives. The results point out the relevance of a Hybrid Practical Value Model consistent to a cyclical notion of the evaluation instead of a linear one.

4 - Developing hypothesis of reuse for abandoned urban areas: a combined application of Strategic Choice Approach and Analytic Network Process
Isabella Lami, Marta Levantesi

The adaptive reuse of abandoned urban areas is a urban,economic and social challenge. In the case of dismissed hospitals, the problem is even exacerbated, mainly because of the peculiar characteristics of the buildings and the distribution of the spaces; and secondly because of the location and the connections in the urban fabric. The paper presents an innovative approach to the problem, with the integration of Strategic Choice Approach (Friend and Hickling, 2005) and Analytic Network Process (Saaty, 2005). The approach has been applied to a current case study, the Civil Hospital of Fermo (central Italy), which is going to be dismissed. The first two phases of SCA (Shaping mode and Designing mode) has been applied individually (by the authors) and in groups (with MSc students of Politecnico di Torino), to develop possible decision scenarios of transformation of the area. Decision schemes, based on architectural decision options, were used as alternatives in the ANP network. Considering architectural, urban, social and economic aspects as criteria, a questionnaire was realized and submitted to specialists (the Mayor of Fermo, two representatives of the Municipality and two representatives of the Public Health Company) to compare the alternatives. The preferred scenario was identified. This application shows how the combination of SCA and ANP could be a valid tool to support decisions in case of adaptive reuse of buildings at urban/architectonic scale.

■ TD-51
Tuesday, 14:30-16:00 - William Fry

Optimal Control Applications 4

Stream: Optimal Control Theory and Applications
Invited session
Chair: Konstantin Kogan

1 - How to deal with Brexit: optimal policy responses in a noncooperative dynamic game
Dmitri Blueschke, Klaus Weyerstrass

In this paper we apply the dynamic games framework to analyse policy reactions to an exogenous shock in the EU. At the end of March 2019 the UK will leave the EU. In a recent study, the Bank of England came up with estimates of possible impacts of this event on the UK economy in various scenarios differing in the assumptions about the form of the new relationship between the UK and the remaining EU. In the most drastic scenario, by 2023 real GDP in the UK could be between 4.75 and 7.75 percent lower than in the case with the UK remaining in the EU. This would also impact on the remaining EU countries. We use an estimated four-country macroeconomic model of an economic union. We call it EUMod, although it contains only the four countries Germany, France, Italy and the UK. For each country, the model contains behavioural equations for GDP, employment, wages, and prices. Furthermore, fiscal policy instruments of the countries are included and monetary policy conducted by the Bank of England for the UK and by the ECB for the three euro area countries is accounted for. We assume different shocks to real GDP in the UK and EU upon Brexit. Applying the OPTGAME algorithm, we then calculate solutions for two game strategies as reaction to this exogenous shock: one cooperative (Pareto optimal) and one non-cooperative game type (the Nash game). EUMod in combination with OPTGAME allows us to analyse interactions between the fiscal policy-makers and the central banks.

2 - **On the optimality of the yardstick regulation in the presence of dynamic interaction**
Michele Bisceglia, Roberto Cellini, Luca Grilli

This paper proposes a generalization of the Shleifer (RAND, 1985) model of yardstick competition, to a dynamic framework. Specifically, we consider a differential game and we show that the static yardstick rule is able to replicate the first best solution, only if players adopt open-loop behaviour rules and they are symmetric at the initial time; in the absence of initial symmetry, the social efficiency is reached only in the asymptotic steady state. If players adopt Markovian closed-loop behaviour rule, the static yardstick pricing rule is not able to achieve the first best solution along the equilibrium path of any stationary Markov Perfect Nash Equilibrium. Finally, we deal with the dynamic price regulation issue in a more realistic set-up with quality competition in a Hotelling framework (Brekke et al., JEMS, 2012).

3 - **Cheating or delighting customers on product quality?**
Fouad El Ouardighi, Konstantin Kogan, Dieter Grass

In this paper, we claim that, though based on different tradeoffs, cheating and delighting policies are the two faces of the same coin. Cheating relies on inflated goodwill and provides a cheating rent as long as the cheating is not disclosed, while delighting benefits from enhanced goodwill and yields a delighting rent as soon as the delighting is awarded. The conditions that allow for rent equalization between the two policy options are identified. We also characterize the conditions under which either cheating or delighting customers on quality is beneficial.

4 - **False quality claims and supply chain implications**
Konstantin Kogan, Fouad El Ouardighi

False quality claims have recently rocked the automobile industry. To promote customer demand while seemingly complying with regulations, manufacturers may cheat even at the risk of incurring severe penalties. As a result, the production horizon becomes uncertain. We study dynamic production policies under such a threat and find that given a specific accuracy in measuring or testing a product's quality, the government or regulatory department can determine a minimal finite penalty to prevent the manufacturer from cheating. However, the smaller the gap between the false claim and the true quality, the greater the penalty must be to prevent cheating. In the context of an underlying supply chain, vertical competition between the manufacturer and its suppliers can play a socially positive role by reducing the batch produced under a false quality claim.

Tuesday, 16:30-17:30

■ TE-01

Tuesday, 16:30-17:30 - O'Reilly Hall

William Cook

Stream: Plenaries
Plenary session
Chair: *M. Grazia Speranza*

1 - **The traveling salesman problem: postcards from the edge of impossibility**
William Cook

Given a collection of points, the TSP asks for the shortest route to visit them all. Simple enough. But even a whisper of the problem strikes fear in the heart of the computing world. Last year, a Washington Post article reported it would take "1,000 years to compute the most efficient route between 22 cities." This claim, however, ignores 70 years of intense study in the OR community. A 22-city TSP can be handled in a snap with modern algorithms, even on an iPhone. Going larger, we describe techniques that have been used to solve to precise optimality examples with nearly 50,000 points and Google Map walking distances. And if you need to visit the nearest 2,079,471 stars, there is a route, ready to go, that is guaranteed to be no more than 1.00002 times longer than a shortest possible tour.

This work follows a long line of computational research going back to Julia Robinson in 1949 and Dantzig, Fulkerson, and Johnson in 1954. The general setting is the following. Complexity theory suggests there are limits to the power of general-purpose computational techniques, in engineering, science and elsewhere. But what are these limits and how widely do they constrain our quest for knowledge? The TSP can play a crucial role in this context, demonstrating whether or not focused efforts on a single, possibly unsolvable, model will produce results beyond our expectations.

We will discuss the history of the TSP and its applications, together with recent computational efforts towards exact and approximate solution methods. The talk is based on joint work the David Applegate, Daniel Espinoza, Marcos Goycoolea, and Keld Helsgaun.

Wednesday, 8:30-10:00

■ WA-01

Wednesday, 8:30-10:00 - O'Reilly Hall

Sheetal Silal

Stream: Tutorials
Tutorial session
Chair: *Theodor Stewart*

1 - Evidence-based tools to support decision making for malaria elimination
Sheetal Silal

With increases in computing power and renewed efforts in the global fight against diseases like malaria, dengue and TB, mathematical modelling is fast becoming a tool to guide public health policy. This talk will focus on the application of mathematical modelling and computer simulation to predict the dynamics of malaria to evaluate the potential impact of policy in reducing morbidity and mortality. Particular attention will be paid to the development of tools to communicate modelling results and support decision-making. Two case studies will be presented: (1) Malaria Elimination and Costing in the Asia-Pacific; a study of malaria dynamics in the 22 countries of the Asia-Pacific and (2) Malaria Strategy Design; supporting the development of a focal malaria elimination strategy. These tools aim to make mathematical models more accessible to policy-makers and serve to bring quantitative tools into the decision-making process.

■ WA-03

Wednesday, 8:30-10:00 - Q106

How can better governance save the world with the help of OR?

Stream: Practice of OR (Making an Impact)
Tutorial session
Chair: *Cathal MacSwiney Brugha*

1 - How can better governance save the world with the help of OR?
Joaquim Gromicho, Cathal MacSwiney Brugha, Iris van Beuzekom, Ulrike Reisach, Dick den Hertog, Dennis Huisman

This panel is a joint effort of the streams on Governance Analytics and Making an Impact, on the Practice of OR. The united nations just published an alarming report https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/ showing that mankind not only leads to an accelerated rate of extinction of species but is orchestrating its own extinction, unless a dramatic change occurs. This calls for effective global governance measures. Intentions are however not enough, for instance agreeing on an amount of emission reduction is not the same as knowing how to reach such objective. Resources are also unequally distributed: we produce more than enough food to feed mankind, nevertheless more than 10% of the world is starving. Careful planning may lead to bringing food to those that need it at low cost and on time. Means of mass transportation have a lower environmental impact but are difficult to plan to the full extent of their potential. Huge opportunities for OR to develop the instruments that effective governance may use to improve the condition of our planet. The panel brings together experts in governance, sustainability, energy, societal impact, mass transportation, defense against the forces of nature and on how to effectively feed the world. The panel includes recipient of past Frans Edelman awards for impact on profit, people and planet. The panel discussion is started by Cathal MacSwiney Brugha, the panel members are: • Cathal MacSwiney Brugha, Emeritus Professor of Decision Analytics, University College Dublin, President, Analytics Society of Ireland. • Ulrike Reisach, plenary speaker at https://www.euro2019dublin.com/plenary-speakers and active in international strategy development and societal, institutional, cultural and ethical issues. • Iris van Beuzekom, sustainability officer of ORTEC, company that was part of the team recipient of the Franz Edelman award in 2012 https://www-informs-org.vu-nl.idm.oclc.org/Recognizing-Excellence/Award-Recipients/TNT-Express and researching transition of multiple related energy networks. • Dick den Hertog, plenary speaker at EURO, https://www.euro2019dublin.com/plenary-speakers, recipient of Franz Edelman award in 2013, https://www-informs-org.vu-nl.idm.oclc.org/Recognizing-Excellence/Award-Recipients/Dutch-Delta-Program-Commissioner and involved in optimizing toward the zero-hunger objective of the World Food Program, https://www1.wfp.org/zero-hunger • Dennis Huisman, recipient of Franz Edelman award in 2008, https://www-informs-org.vu-nl.idm.oclc.org/Recognizing-Excellence/Award-Recipients/Netherlands-Railways2 and an expert on optimizing mass transportation networks.

■ WA-04

Wednesday, 8:30-10:00 - Q116

Teaching OR/MS 5

Stream: OR Education
Invited session
Chair: *Luke Connolly*

1 - Assigning the Right Weights in Student Evaluation of Teaching via AHP - A Case Study
Baruch Keren, Yossi Hadad, Gali Naveh

Student evaluation of teaching (SET) is usually used to evaluate and to improve higher education teaching quality. Moreover, the data from these evaluations are often used for making decisions that affect the academic staff's career. The commonly used tool for this process is a multi-criteria questionnaire that typically assess student perceptions of course organization, teaching methods, student workload, grading, communication with students, enthusiasm of the teacher and/or other course's values in terms of learning. Under this framework the purpose of this is research is: 1) To set via the Analytic Hierarchy Process (AHP) the right weight for each selected evaluation criterion from the students and from the lecturers point of views. 2) To explore via a real case study the distribution of the grades among the criteria. For these purposes, we conducted a survey that captures the students and lecturers opinions on the relative importance of various teaching components using the AHP methodology. Then we analyzed the SET that used the given selected criteria. The research reveals that the weights of the evaluation criteria of students and lecturers are significantly different, and that the variance among the evaluation criteria in each questionnaire is low. These results may have theoretical and managerial implications.

2 - The European survey on OR/MS Education: statistical analysis addressing the lecturing modules
Joao Miranda, Ana Paula Teixeira, Margarida Pato

This work addresses the European survey conducted with the aim of learning from the most recent developments in the Higher Education area concerning the Operational Research/Management Science (OR/MS) field. This regards, in particular: (i) the enrolment of students; (ii) the 1st year students' failure rates and the promotion of continuity; (iii) the perceived value of OR/MS courses; (iv) the OR/MS teaching practices; and (v) the transition of graduates onto the Labour

Market. The survey results are revisited, and a statistical analysis is performed to understand if there is a relation of the respondents' perceptions ("Positive" and "Negative") and the types of OR/MS modules that were lectured at their institutions (type-A, bachelor/master programmes; type-B, separate majors/minors, and type-C, courses). The results analysis of independence tests is presented; it can be observed that most of the queries concerning the restructuring procedures are weakly related with the lectured types of OR/MS modules and the same happens with half of the queries regarding the approaches within 1st year students. The opposite happens with the labour market responses, as all of them are independent of the lectured types of OR/MS modules. Both for the enrolment of students and for the teaching practices, a third of the responses received are related with the lectured types of OR/MS modules, although weakly. Further developments within the evidence-based approach are discussed too.

3 - Academic Writing: How to Fail Better
Luke Connolly

Writing is always a difficult, painful and torturous affair. Over the ages, philosophers and scientists alike have often arrived at the same self-evident conclusion: we are speaking beings, not writing beings. Speaking comes naturally, writing does not. Thankfully, there are ways of alleviating the pain inevitably incurred by the writing process. Having worked closely with an Operational Research group as a proofreader and editorial consultant over the past four years, I have helped guide a vast number of research papers from their first drafts all the way through to their published versions. Not being a practitioner of OR myself, this experience has provided me with a uniquely disinterested perspective as regards academic writing in the discipline. During this talk I will offer general insight regarding what I have come to see as four key aspects of the academic writing process, namely: (i) the (non)linear path of the research paper, (ii) determining and communicating value, (iii) structuring and (iv) the necessity of re-learning your insight. While my advice is geared towards younger researchers, it should also prove useful for those in supervisory roles who are struggling with what might sometimes feel like the needlessly difficult and inefficient process of getting their students' work to a publishable standard.

■ WA-05

Wednesday, 8:30-10:00 - A003

Risk Analysis

Stream: Decision Analysis
Invited session
Chair: Ahti Salo

1 - Estimating the probability of a major power system unreliability event - a Structured Expert Judgement Elicitation approach
Martine Barons, Tim Bedford, Keith Bell, Abigail Colson, Simon French

Preventing, containing and recovering quickly and safely from disturbances to the power system, is essential. Security standards and defence plans are in place worldwide but how often might a system collapse and black start be required? Major events remain very rare and have shown a number of common phenomena, but the precise pathway is different each time and depends on complex and uncertain system behaviour and characteristics. The use of modelling to estimate the probability of system shutdown is therefore extremely difficult. We describe a Structured Expert Judgement (SEJ) approach. SEJ is used where major risks need to be understood in respect of phenomena that are not readily amenable to modelling. We develop a conceptual, high-level model of the power system and use it as the basis for questions to elicit the judgements of relevant experts. Facilitated discussion tests experts' buy-in to the model, understanding of the questions, and highlights the range of scenarios included. SEJ allows not only the elicitation of each expert's own judgement, but also the assessment of the experts' abilities to estimate a probability and an uncertainty range within which they believe the true answer lies. This is used in weighting experts' answers to the main questions of interest. Experts are given the opportunity to share rationales and discuss the questions in two rounds to enable enhanced understanding of the situation and to adjust assessments based on these insights.

2 - An Adaptive Rule-Based DSS For The Container Space Allocation Problem Under Uncertainty
Jana Ries, Rosa G. González-Ramírez, Maurizio Faccio

Container ports are operating under increasingly stringent resource conditions given the continuously growing number of containers transported globally. Meanwhile, the ability to ensure sufficient predictability with respect to relevant social, economic and environmental factors to ensure efficient planning keeps declining. As a consequence, the need of adaptive decision support systems in the context of operational decision making within a container port has become of growing importance.

The work focus on the container space allocation problem which aims to identify the best allocation strategy to place containers within a container yard while ensuring that operational efficiency is maximised. A decision support system design is proposed to dynamically select suitable decision criteria based on a real-time impact assessment of uncertainty within the container port. The design exploits the relationship between the degree of agility of a decision rule and the level of uncertainty in the port. The presentation will outline computational results based on a real-world case study.

3 - A Receiver Operating Characteristics (ROC) point of view to compare different binary decision criteria. Application to solve the doctrinal paradox.
Mercè Farré, Aureli Alabert

Often, a parametric probability model may be used to describe binary decision rules, perhaps simplified. Assume tat the false positive rate (FPR) and the false negative rate (FNR) can be deducen from the model as a function of the parameters values. In this case, the ROC graph can be used to compare the rules, computing analitically or numerically the regions in the parameters space that made a specific rule to be optimal. Just as an example, consider a committee or jury facing a compound question divided in two subquestions or premises. Doctrinal paradox arises when a given set of individual decisions leads to different collective decisions under different aggregation rules. This setting can be described by means of a probability model depending on the committee size and the competences of the committee members. Then, the two most famous rules, known as issue-by-issue (IbyI) and case-by-case (CbyC), might be compared on the ROC graph. We have shown that the IbyI rule is uniformly optimal for all values of competence and size parameters, if FPR and FNR are considered to be of equal relevance weight or if FPR penalizes less than FNR. Non-uniform results are described if FPR is penalized with a larger weight than FNR.

4 - Decision Programming for Optimizing Multi-Stage Decision Problems Under Uncertainty
Ahti Salo, Juho Andelmin, Fabricio Oliveira

Multi-stage problems under uncertainty can be represented as influence diagrams consisting of decision, chance and value nodes connected by arcs. At each decision node, the solution can be derived either by transforming the diagram or by solving the equivalent decision tree with dynamic programming. Both approaches assume that earlier decisions are known when making later ones, which may not be the case in distributed problems. Moreover, dynamic programming is restrictive in that optimal strategy within a given branch cannot depend on the decisions in other, non-overlapping branches. Thus, the objective function cannot include risk measures such as semi-absolute deviation which would capture the variability of consequences over all branches. Interdependencies between branches arise in project portfolio selection, too, because the use of shared resources implies that decisions for one project depend on those for others.

In this paper, we develop the Decision Programming approach for multi-stage decision problems which can represented as extended influence diagrams without the 'no forgetting' assumption in the presence of multiple objectives and constraint types. This approach also extends Contingent Portfolio Programming (Gustafsson and Salo, Oper. Res., 2005) to the selection of projects which can impact scenario probabilities. It is efficient enough for problems of realistic size, because the solutions can be obtained with mixed-integer linear programming (MILP).

■ WA-06

Wednesday, 8:30-10:00 - A004

Optimization models for operating integrated energy systems

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Yelena Vardanyan

1 - Operational Planning and Bidding under Uncertainty for District Heating Systems
Ignacio Blanco, Daniela Guericke, Anders N. Andersen, Henrik Madsen

In countries with an extended use of district heating (DH), the integrated operation of DH and power systems can increase the flexibility of the power system achieving a higher integration of renewable energy sources (RES). DH operators can not only provide flexibility to the power system by acting on the electricity market but also profit from the situation to lower the overall system cost. However, the operational planning and bidding includes several uncertain components at the time of planning: electricity prices as well as heat and power production from RES. In this presentation, we propose a planning method that supports DH operators by scheduling the production and creating bids for the day-ahead and balancing electricity markets. We apply our solution approach to a real case study in Denmark and perform an extensive analysis of the production and trading behavior of the DH system. The analysis provides insights on system costs, how DH system can provide regulating power and the impact of RES on the planning.

2 - Operating Microgrids with High Penetration of Renewable Energy units
Frederik Banis

We present Microgrid real-time controllers optimized for high penetration of Renewable Energy Sources using Model Predictive Control. The active power control incorporates both direct-control and indirect-control approaches. In the direct control scheme, real-time optimal system trajectories are derived using a Predictive Adaptive Disturbance Rejection Controller and passed to directly controlled system units. The indirect control scheme includes response estimation strategies in temporal clusters in order to allow for a real-time re-dispatch in periods of increased need for flexibility. We incorporate long-term predictions of uncertain processes and optimal system trajectories using an Energy Management System posed as Stochastic Program. We aim to allow for the overall system operation as Virtual Power Plant and participation in various energy and service markets.

3 - Stochastic Bilevel Program for Optimal Coordinated Bidding of a Profit Maximizing EV Aggregator
Yelena Vardanyan, Henrik Madsen

This paper proposes s stochastic bilevel optimization problem based on the Stackelberg game to create price incentives for generation of optimal bids for a profit-maximizing EV aggregator in day-ahead, intraday and real-time markets. The upper level represents the profit maximizer EV aggregator participating in three sequential markets, called a Stackelberg leader, while the second level represents the EV owners aiming at minimizing the EV charging cost, also called a Stackelberg follower. This formulation determines endogenously the profit-maximizing price levels constraint by cost-minimizing EV charging plans. To solve the proposed stochastic bilevel program, the second level is replaced by its optimality conditions. The complementary slackness condition is replaced by the strong duality condition. The final model is a stochastic mixed-integer linear programming (MILP) which can be solved efficiently to the global optimality. Illustrative results are reported studying a small case with two vehicles. The numerical results relies on applying the proposed methodology to a large scale fleet of 500 vehicles providing insights on computational burden of the curret formulation.

4 - Control-based Provision of Ancillary Services by Flexible End-Users
Giulia De Zotti, Seyyed Ali Pourmousavi Kani, Juan Miguel Morales, Henrik Madsen

This paper presents a hierarchy of procedures to exploit consumers' flexibility for the provision of ancillary services (AS) (i.e., voltage and frequency regulation) in power systems operation. The proposed framework relies on a control-based approach that adopts prices as economic incentives to modulate consumers' response. Prices are issued both at the transmission and distribution levels independently. An artificial neural network is used by the TSO to infer the price-consumption reaction from pools of consumers located downstream. The DSO uses a PI controller to model the consumers' price response and generate time-varying electricity prices. Simulation results show the applicability of the proposed method for the provision of AS from consumers at different levels of the grid.

■ WA-07

Wednesday, 8:30-10:00 - A007

OR in Forestry II

Stream: OR in Agriculture and Forestry
Invited session
Chair: Isabel Martins

1 - Optimizing the deployment of aerial resources for wildfire initial attack
Joao Zeferino

The protection of forests is increasingly important. With climate change there are increased droughts and extreme temperatures. In result, serious threats, such as severe wildfires, are more recurrent and devastating. Aerial firefighting resources are crucial to quickly contain dangerous fire occurrences through an initial attack consistent with the safety of life and property. This contribution develops an optimization model for the deployment of aerial firefighting fleets for wildfire initial attack. It considers all the forests within a region and their predefined wildfire hazard potential. The objective to be maximized is wildfire hazard coverage, considering the amount of aircraft covering each area, their characteristics and their distance to those covered areas. The model allows specifying resource constrains such as the fleet and air bases available. A piecewise linear approximation is applied to nonlinear functions, and the model is reformulated into a mixed integer programming problem. As a result, it is possible to obtain exact solutions. Two case studies of different regions affected with recent major wildfire events are presented and analyzed. These case studies illustrate the potentialities of the model in real-world situations.

2 - Conversion form pure to mixed forest stands in the Czech Republic: Forest managers' decision making
Jitka Janova

Conversion from pure coniferous to mixed forest stands is of highest importance for ecologically sustainable forestry in Central Europe. While there is a broad consensus that the conversion should be implemented without delay, the conversion process is too slow in the Czech Republic. The problem stems mainly from the economic dimension: the pure coniferous stands are economically advantageous and even though the mixed forests are supposed to be economically comparable, the long run conversion process has unknown economic impacts.

We present the problem of the optimal long run subsidy policy in the Czech Republic that would effectively support conversion into the mixed forest stands. Particularly, we present (i) the results of quantitative research on forest managers' decision making regarding the conversion process , (ii) formalization of the qualitative relations in the form of constraints in the optimization model and (iii) the results of the dynamic programming model.

3 - Impacts on Irish forestry from climate change and an expanding bioeconomy - using linear programming to solve complex forest management problems
Anders Lundholm, Edwin Corrigan, Maarten Nieuwenhuis

Forest managers must comply with sustainable forest management practices, including planning for long-term impacts of global change. Remsoft Woodstock was used to build a decision support system (DSS) for Ireland's Western Peatland forests. The DSS was built to analyse potential impacts on forest management from three global scenarios with various degrees of climate change (CC) and increasing timber prices from an expanding bioeconomy. Linear programming (LP) was used to maximise net present value (NPV) over a 100-year planning horizon, using a 5% discount rate. Three constraint sets were included: to avoid over-harvesting, to ensure replanting after clearfelling, and to establish buffer zones. The study area contained 9,899 ha of forest in 2,777 polygons. The generated LP matrix model contained around 2,340,000 columns, 673,000 rows, and took around 5 hours to solve using 32 GB RAM and a 3.20GHz processor with 6 dual-thread cores. The results showed an NPV increase of 26 to 58% in the scenarios with global change, compared to no changes. The model was also run with CC but without dynamic prices, and vice versa. These runs showed that CC had a negative impact on NPV (decreasing NPV by 7% in one scenario), while the dynamic timber prices resulted in an increase in NPV. This study demonstrated that implementation of CC and dynamic timber pricing in a forest management DSS is feasible and straight-forward, but that reliable data on future conditions are essential.

4 - A heuristic based on branch-and-cut for spatially constrained harvest scheduling with multiple harvests
Isabel Martins, Susete Marques, Marlene Marques, Marco Marto

Spatially constrained harvest scheduling with multiple harvests are mostly solved with heuristics that do not provide the deviation of the solutions from the optimum. In this work, we propose an approach for harvest scheduling with multiple harvests subject to constraints on clearcut area that measures the quality of the solutions, based on the branch-and-cut method. The approach was tested on two real forest data sets with 1137 and 789 stands, about 55 and 33 alternative prescriptions per stand and more than four harvests per prescription in average, over a 100-year planning horizon with 10-year periods. Computational results are reported.

■ WA-08

Wednesday, 8:30-10:00 - A008

Advances in Robust and Stochastic Optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: Chungmok Lee

1 - Optimizing under Uncertainty with Probing Costs
Chungmok Lee

We consider optimization problems where the data defining the problem are uncertain. It is assumed that initially the uncertain data are given as ranges and probing the true values of data incurs some cost. Our aim is to minimize the probing cost while guaranteeing a certain level of solution quality. We introduce the concept of Gamma-optimality: proving of additional Gamma true values cannot improve the solution at hand. We propose an iterative method to identify which uncertain data should be chosen to be probed for reducing the total probing costs. Some theoretical results on the robustness of the solution also will be presented.

2 - A heuristic algorithm for the chance constrained knapsack problem using submodularity
Seulgi Joung, Kyungsik Lee

In this presentation, we consider a chance constrained knapsack problem (CKP), where the weights of items are independent normally distributed. We propose a robust optimization-based heuristic algorithm for the CKP. Using submodularity, we approximate the CKP to the robust knapsack problem with a cardinality constrained uncertainty set. The proposed method obtains a heuristic solution by solving the approximated robust knapsack problem iteratively. The computational results show the effectiveness and efficiency of the proposed method.

3 - An approximation algorithm for a probability maximization knapsack problem
Jisun Lee, Seulgi Joung, Kyungsik Lee

Chance-constrained knapsack problem (CCKP) is the problem of choosing a set of items to maximize the total profit while guaranteeing the probability of satisfying the capacity constraint is at least a given threshold. In this talk, we consider a probability maximization knapsack problem (PMKP) which is closely related to CCKP. The problem is to determine a set of items that maximizes the probability of satisfying the capacity constraint subject to the constraint of the total profit to be at least a given value. We investigate the relationship between PMKP and CCKP, and analyze the complexity of PMKP based on that. We also propose an approximation algorithm for PMKP that can be a FPTAS for special cases, and present experimental results of the algorithm.

4 - Data-Driven Distributionally Robust Capacitated Facility Location Problem
Ahmed Saif, Erick Delage

We address a stochastic version of the Capacitated Facility Location Problem (CFLP) when the probability distribution of demand is not known with certainty but can rather be estimated based on a finite sample of observations. A distributional ambiguity set is constructed around the empirical distribution, formed based on the historical data, such that it includes all distributions within a certain distance from the reference distribution, where distance is measured using a Wasserstein metric. A distributionally robust optimization (DRO) approach is implemented to hedge against uncertainty and find solutions that provide probabilistic out-of-sample performance guarantees. Both single- and two-stage problems are considered. With proper selections of the support set and the norm used in the Wasserstein metric, both cases can be tractably reformulated as mixed-integer linear programs. For the two-stage problem, we devise an exact column-and-constraint generation algorithm that is quite efficient for medium size problems. Moreover, we propose a conservative approximation of the two-stage problem using affine decision rules that can handle large-scale problems. Extensive numerical testing on standard instances from the literature was conducted to evaluate the solutions obtained from the exact single-stage, exact two-stage and approximate two-stage formulations using out-of-sample data and evaluate the computational performance of the column-and-constraint generation algorithm.

■ WA-09

Wednesday, 8:30-10:00 - B006

Performance Measurement III

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Dimitrios-Georgios Sotiros*

1 - Efficiency valuation of stocks and green portfolio construction: a two stage approach
Antonella Basso, Giorgia Oggioni, Rossana Riccardi

In this contribution we select and manage a green investment portfolio that integrates classical financial tasks with environmental issues. We first propose two synthetic indicators of environmental sustainability of stocks that overcome the drawback that limits the evaluation of green investments to the measurement of CO2 emissions. Then, we propose an integrated method for portfolio optimization that involves decisions on stock screening, stock selection, and capital allocation. A two steps approach is adopted: in the first step a wide set of relevant stocks are screened in order to find a group of potential investment targets that are simultaneously profitable and green. In the second step we apply a portfolio optimization model to determine the asset allocation in the portfolio. The first step of the procedure is aimed at detecting the more promising stocks according to both a financial and an environmental performance and use a use a suitable DEA model with weights restrictions. The subset of best performing stocks will be used in step 2 for creating the green portfolio. The second step of the analysis is the creation of the green portfolio with a portfolio selection algorithm for asset allocation. Three different portfolio selection algorithms have been tested: Markowitz, MAD and CVaR. A dynamic implementation of the algorithm is also proposed.

2 - Performance Measurement of Efficiency in the City Councils in Chile
Hanns de la Fuente-Mella

Measure efficiency of the City Councils in Chile are fundamental to the country's decentralization by introducing a more productivity route of administration along with people. The factors that make it efficient and improve the quality of citizens' life are essential. In Chile there are 346 city councils which belong to the different communes, for the following research there were selected the ones that have more than 50,000 habitants and that belong to regional capitals. The factors that influence the efficiency and performance of the city councils in Chile were determined and modeling using econometrics stochastics method, using as endogenous variable the index of quality of life in the communes. Therefore, there was developed an econometric model which explained the determined factors for the efficiency of the city councils in Chile. Moreover, there were identified the variables that have a greater impact on such efficiency.

3 - Ranking in two stage dea models
Clara Simon de Blas, Jose Simon Martin

In this work, we propose a method for ranking decision-making units (DMUs), for two stage network models, based in measures of dominance derived from multilayered social network analysis, in combination with data envelopment analysis (DEA). For this purpose, a directed and weighted multilayered graph is constructed, in which the nodes represent the system's DMUs and the edges represent the relationships between them. The objective is to identify and rank the most important nodes by taking into account the influence or dominance relations between the DMUs. The method uses a weighted HITS algorithm to identify the hubs and the authorities in the multilayered network by assigning to each DMU two numbers, the authority weight and the hub weight. The proposed method is highly flexible to adapt in two stage network models from independent to fully dependent intermediate products.

4 - The Composition approach in Network Data Envelopment Analysis for parallel structures
Dimitrios-Georgios Sotiros, Gregory Koronakos, Maria Silva, Dimitris Despotis

Data Envelopment Analysis (DEA) is a non-parametric technique for measuring the efficiency of Decision Making Units (DMUs). However, standard DEA models treat the DMU as a "black-box" i.e., only the levels of the inputs that the DMU utilizes and the levels of the outputs that it produces are known. Nevertheless, in most cases the internal structure of the DMU is known and plays a crucial role in the efficiency assessment. In such a case, the unit is composed by several sub-units (divisions), which are arranged either in a series, parallel, or mix structure. Network DEA is an extension of the conventional DEA to assess the efficiency of DMUs by taking into consideration their internal structure. In this paper, we focus on parallel structures and we revisit existing approaches in the literature. We unveil that these approaches violate some properties that all network DEA models should comply with and thus they may provide misleading results. Then, we introduce the composition approach in parallel structures to overcome these issues and to provide reliable results. Our new approach relies on concepts of Multi-Objective Programming and the divisional efficiencies are estimated first whereas the overall efficiency derives ex-post from the aggregation of the sub-units' efficiencies. Illustration of our approach and comparison with the standard approach are also provided through numerical examples.

■ WA-10

Wednesday, 8:30-10:00 - H0.12

Derivative-free Optimization: Methods and Applications in Industrial Problems

Stream: Derivative-free Optimization
Invited session
Chair: *Riccardo Pellegrini*
Chair: *Matteo Diez*

1 - Parallel Hybrid Multiobjective Derivative-Free Optimization for Machine Learning
Steven Gardner, Oleg Golovidov, Joshua Griffin, Patrick Koch

With the exponential growth rate of digital data, the challenge of managing, understanding, and capitalizing on this data continues to grow. Machine learning modeling algorithms are commonly used to find hidden value in big data. These algorithms are governed by hyperparameters with no clear defaults agreeable to a wide range of applications. Ideal settings for these hyperparameters significantly influence the resulting accuracy of the predictive models. In this talk we discuss the use of constrained derivative-free optimization for automated hyperparameter tuning. We present our Local Search Optimization (LSO) framework which implements a parallel hybrid derivative-free optimization strategy for problems with functions that are nonsmooth, discontinuous, or computationally expensive to evaluate directly. We also show how our initial tuner has been extended to make use of constrained multiobjective optimization techniques. We present tuning results for multiple examples.

2 - High-end parametric models for faster simulation-driven design
Hedi Boettcher, Stefan Harries

The contribution focuses on the parametric modeling and automated optimization of several elements of a high-end turbocharger such as the turbine, compressor, diffusors, volutes and ducts. The turbocharger is a key component of a gas engine by MTU which is used, for example, for marine propulsion and (emergency) power generation. The optimizations shown are multi-objective in order to achieve higher efficiency, a broader operating map and lower weight.

Sophisticated parametric models will be discussed which define both the fluiddynamic domain and the structural domain for CFD and FEA analyses, respectively. The processes to undertake the design campaigns bring together various commercial software systems, most notably CAESES for parametric modeling, FINE/Turbo and FINE/Open for fluiddynamics simulations, CALCULIX for structural analyses and modeFRONTIER for integration and optimization strategies. The optimizations, for instance for the turbine, have resulted in considerable improvements in efficiency and increases in the operating map while reducing mass and moment of inertia.

Methods to reduce the number of free variables will be considered in the context of simulation-driven design (SDD), namely Karhunen-Loève Expansion (KLE) to substantially reduce design spaces. The transformation from CAD spaces to KLE spaces and back, as realized within CAESES, will be elaborated on.

3 - Dense versus Sparse Initializations for Deterministic Particle Swarm Optimization in Applications
Giovanni Fasano, Matteo Diez, Andrea Serani, Riccardo Gusso, Emilio Fortunato Campana, Cecilia Leotardi

We describe a class of novel initializations in Deterministic Particle Swarm Optimization (DPSO) for approximately solving costly unconstrained global optimization problems. The initializations are based on choosing specific dense initial positions and velocities for particles. These choices tend to induce in some sense orthogonality of particles' trajectories, in the early iterations, in order to better explore the search space. Our proposal is inspired by both a theoretical analysis on a reformulation of PSO iteration, and by possible limits of the proposals reported in the literature. We explicitly show that, in comparison with other initializations for PSO, our proposal tends to scatter PSO particles, at least in the early iterations. The latter goal is obtained by imposing that the initial choice of particles' position/velocity satisfies specific conjugacy conditions, with respect to a matrix depending on the parameters of PSO. In particular, by an appropriate condition on particles' velocities, our initializations also resemble and partially extend a general paradigm in the literature of exact methods for derivative-free optimization. Moreover, we propose dense initializations for DPSO, so that the final approximate global solution obtained is possibly not too sparse, which might cause troubles in some applications. Numerical results, on both Portfolio Selection and Computational Fluid Dynamics problems, validate our theory and prove the effectiveness.

4 - Derivative-free line-search algorithm for variable-accuracy optimization
Riccardo Pellegrini, Giampaolo Liuzzi, Stefano Lucidi, Francesco Rinaldi, Andrea Serani, Danny D'Agostino, Matteo Diez

We propose a derivative-free algorithm of the line-search type specifically developed for objective functions provided by a simulator with variable accuracy. On the basis of an internal stepsize parameter, the algorithm automatically adjusts the precision imposed to the simulator. In this way, accurate and costly simulations, i.e. those run with a fine precision, are only used when the stepsize parameter is approaching convergence. The method is coupled with a computational fluid dynamics (CFD) solver whose accuracy is determined by the computational grid size. For the current demonstration, a potential flow solver is adopted. The application is the resistance optimization of the 5415 DTMB (an early and open to public version of a USS Arleigh Burke-class destroyer) hull form using 27 shape parameters as design variables.

■ WA-11

Wednesday, 8:30-10:00 - H1.12

Mixed-Integer Bilevel Problems

Stream: Mixed-Integer Nonlinear Programming
Invited session
Chair: Martin Schmidt

1 - Computing Stationary Points of Mixed-Integer Bilevel Problems with a Penalty Alternating Direction Method
Thomas Kleinert, Martin Schmidt

Bilevel problems are highly challenging optimization problems that appear in many applications of energy market design, critical infrastructure defense, transportation, pricing, etc. Often, these bilevel models are equipped with integer decisions, which makes the problems even harder to solve. Typically, in such a setting in mathematical optimization one develops primal heuristics in order to obtain feasible points of good quality quickly or to enhance the search process of exact global methods. However, there are comparably few heuristics for bilevel problems. In this talk we present such a primal heuristic for bilevel problems with mixed-integer quadratic or linear upper level and continuous convex-quadratic or linear lower level. The heuristic is based on a penalty alternating direction method, which allows for a theoretical analysis. We derive a convergence theory stating that the method converges to a stationary point of an equivalent single-level reformulation of the bilevel problem. We provide an extensive numerical study and illustrate the good performance of our method both in terms of running times and solution quality.

2 - A Global Penalty Outer Approximation Algorithm for Mixed-Integer Quadratic Bilevel Problems
Martin Schmidt, Thomas Kleinert

Bilevel optimization problems have received a lot of attention in the last years and decades. Besides numerous theoretical developments there also evolved some novel solution algorithms for mixed-integer linear bilevel problems and the most recent algorithms use branch-and-cut techniques from mixed-integer programming that are especially tailored for the bilevel context. In this paper we consider MIQP-QP bilevel problems, ie, models with a mixed-integer convex-quadratic upper level and a continuous convex-quadratic lower level. This setting allows for a strong-duality based transformation of the lower level which yields, in general, an equivalent nonconvex single-level reformulation of the original bilevel problem. Fortunately, under the popular assumption of integer linking variables we can derive a hybrid method combining both outer-approximation based cutting planes and a penalty algorithm. It is shown that this hybrid method convergences to a global optimum of the bilevel problem under reasonable assumptions. Moreover, we present extensive numerical results.

3 - Efficiently Solving Linear Bilevel Programming Problems using Off-the-Shelf Optimization Software
Salvador Pineda Morente, Juan Miguel Morales

Many optimization models are formulated as bilevel problems. Most solution methods reformulate the bilevel problem as a mathematical program with complementarity conditions (MPCC). MPCCs are single-level non-convex optimization problems that do not satisfy the standard constraint qualifications and therefore, nonlinear solvers may fail to provide even local optimal solutions. In this presentation we propose a method that first solves iteratively a set of regularized MPCCs using NL solvers to find a local optimal solution. Local optimal information is then used to reduce the computational burden of solving the Fortuny-Amat reformulation of the MPCC to global optimality using MIP solvers.

■ WA-12

Wednesday, 8:30-10:00 - H1.51

Innovations and Applications in Combinatorial Optimization

Stream: Combinatorial Optimization I
Invited session
Chair: Gary Kochenberger
Chair: Yu Du

1 - Team of Teams: Optimal Algorithm Communication
Oleg Shylo

We consider communicative solvers in optimization that run concurrently and exchange information to boost performance. By synchronizing memory structures with more successful counterparts, the individual algorithms can avoid stagnation and improve overall performance. We develop theoretical models that enable efficient evaluation of communication topologies without empirical testing. Through these constructs we establish communication strategies that are provably optimal.

2 - Minimum Weight Vertex Covering Problems: A Comparison of Models and Solvers
Yu Du, Gary Kochenberger, Fred Glover

Finding good solutions to Minimum Weight Vertex Covering Problems (MWVC) is a NP hard problem. Most existing methods are challenged to find a good solutions in reasonable amount of time. Commercial (exact) solvers have improved tremendously in recent years and the combination of the right solver and the right model can significantly increase our ability to compute acceptable solutions to modest sized problems.

In this paper, we propose an efficient unconstrained binary quadratic programming model for solving the MWVC problem. We compare the use of three commercial solvers and a path relinking type of heuristic method on a set of modest sized test problems for Minimum Weight Vertex Covering Problems. Experimental results on the challenging benchmark instances demonstrate that this general approach is competitive with current state-of-the-art approaches for solving the MWVC problem.

3 - A Computational Study of the Quadratic Knapsack Problem with Multiple Constraints
Gary Kochenberger, Fred Glover, Haibo Wang, Yu Du

The quadratic knapsack problem (QKP) has been a problem that is very difficult to solve despite notable advances in special purpose solution methodologies in recent years. Several linearizations are available for quadratic combinatorial problems. These reformulations recast the quadratic problem into an equivalent 0/1 linear model that can then be solved by methods specially crafted for linear models. Preliminary experiments carried out on one linearization model for solving quadratic knapsack problems led to the observation that the upper bound parameters (U) in the model, if chosen carefully, have the potential to significantly improve the computational efficiency of the model, particularly as problems scale in size. This paper experiments with approaches for strengthening the upper bounds and to assess the impact of the improved bounds of the computational effectiveness of the LIN model. Computational comparisons carried out using CPLEX, with test problems being solved in both original and linearized forms, shows that the methods combining optimal ordering of variables and surrogate constraint heuristics methodologies will improve the upper bounds parameters (U) in the model, thus improved the efficiency of linearization and quadratic representations of QKP.

4 - The Mothership and Drone Routing Problem with Obstacles
Stefan Poikonen, Bruce Golden

The mothership and drone routing problem is a collaborative transportation model between a mothership (e.g., a ship, plane, or other large vehicle that can move by Euclidean distances) and a drone. We show that by combining second order cone programming with the branch-and-bound algorithm, we can find optimal solutions. Additionally, we show fast heuristics that use second order cone programming. We show that the second order cone program can be modified for other constraints. We then consider the case where there exist several polygonal obstacles (e.g., dry land, shallow waters, political boundaries) that restrict the motion of the mothership. These obstacles inject nonconvexity into the feasible domain, which complicates the problem significantly. Our proposed solution method first finds a feasible solution. Afterwards, a sequential second order cone program is applied. This second order cone program contains a new set of constraints. Critically, we circumscribe the launch and landing locations of the drone from the previous iteration's solution with a circle of maximal radius, such that the circle does not intersect with any obstacle. The launch and landing locations of the current iteration are constrained within these circles. Thus, we are able to ensure that the chosen launch and landing locations do not intersect with land, but we are able to preserve the form of a second order cone program.

■ WA-13

Wednesday, 8:30-10:00 - H2.12

Algorithms and Stability of Nonlinear Programming

Stream: Nonlinear Programming. Theory and Methods
Invited session
Chair: *Xiaoqi Yang*

1 - Fully Piecewise Linear Vector Programs
Xiaoqi Yang

Piecewise linear functions appear in many applications such as network flow problems to reflect overload shipment cost and penalties for under supplied or overstocked goods. Piecewise linear programs have been well studied in finite dimensional spaces. In general normed spaces, we classify piecewise linear functions and provide their representations using linear functions. Based on such classification and representations, we study a fully piecewise linear vector optimization (PLP) with the objective and constrained functions are piecewise linear. We divide (PLP) into some linear subproblems. Under some mild assumptions, we prove that the weak Pareto solution set of (PLP) is the union of finitely many polyhedra, each of which is a weak Pareto face (or a subset of a weak Pareto face) of some linear subproblem. In particular, we further generalize Arrow, Barankin and Blackwell's classical results on linear vector optimization problems in Euclidean spaces.

2 - The Aubin Property of Feasible Set Mapping of Linear System Under Perturbations
Wenfang Yao, Xiaoqi Yang

Aubin property is a concept for stability of multifunctions. In this talk, we mainly compare some calculation results on the Aubin property of the feasible set mapping of linear systems under full perturbation and right hand side perturbation by Mordukhovich criterion. Further more, the feasible set mapping with a sparsity constraint is also considered and a sufficient and necessary condition for the Aubin property of such a feasible set mapping is given. A few examples will be given for illustrations.

3 - The Mirror Descent Algorithm with Computational Errors
Alexander Zaslavski

We analyze the convergence of the mirror descent algorithm under the presence of computational errors. We show that the algorithm generates a good approximate solution, if computational errors are bounded from above by a small positive constant. Moreover, for a known computational error, we find out what an approximate solution can be obtained and how many iterates one needs for this.

4 - A penalty proximal alternating direction method of multipliers for the generalized bilinear problem
Chenchen Zu

The generalized bilinear problem is an optimization problem with a bilinear objective function, some bilinear equality constraints and some linear inequality constraints. Related applications appear in plenty of fields such as portfolio, industry, management and so on. In this work, we propose a penalty proximal alternating direction method of multipliers to solve the generalized bilinear problem, in which few algorithms guarantee the convergence. In this algorithm, the proximal term plays an essential role since the ill-conditioned cases caused by the penalty function can be greatly enhanced by correctly selecting the parameter of the proximal term. Theoretically, we establish the global convergence analysis under certain assumptions, provide the result of iteration complexity and investigate the sufficient condition of the existence of the minimum of the generalized bilinear problem. Eventually, we consider our algorithm on some numerical experiments and show the efficiency of our proposed algorithm to the application problems.

■ WA-14

Wednesday, 8:30-10:00 - H2.20

MIP Applications I

Stream: Mixed Integer Programming
Invited session
Chair: *Monique Sciortino*

1 - Mathematical Programming models for Cyber Attack Defense
Sonia Vanier, Céline Gicquel

We purpose in this work new mathematical programming models for the defense against cyber attacks in telecommunication networks. We developed new models based on bilevel programming problems that achieves a tradeoff between security levels requirements and security investment cost. Our results show that this mechanisms overcomes attacks by effectively filtering attacks while minimizing the total cost of deployed security services. We also propose mixed-integer linear program aiming at eliminating all cyber attacks before they reach their target. As the problems size grows exponentially with the networks size, we propose a constraint generation algorithms to solve them. The numerical results obtained for different realistic network instances show the effectiveness of our approach.

2 - A personnel assignment model for the Ecuadorian Police.
Fernanda Salazar, Sandra Gutierrez, Diego Recalde, Polo Vaca

Nowadays, the Ecuadorian Police determines how many police officers have to work in some especified area for a given period of time based on a very basic model that clasifies every area in the country as being of type A or type B without even considering the offer of police services that an area has nor the demand that needs to be served. Here we propose an integer programming model where the objective is to obtain the assignment that maximizes the individual contribution of the officers to the Police as an institution. With this aim, we consider the individual qualifications of the police officers versus the activities they must perform and the place where they will carry out such activities. When modelling the police's environmet, we consider criteria such as the distance between their residences and the working area they are assigned, the experience in years of service that a police has, the level of security of the area where they are assigned and other characteristics such as if they have driver's license for cars or motorcycles. The constraints guarantee conditions about offer, demand and requirements for the activities. The results are relevant for the Police since they will make it possible to assign the personnel more efficiently throughout the country and will reveal other elements such as the deficit they have in order to cover the national seccurity needs. Preliminar computational results indicate that the personnel assigment will have a major improve.

3 - Scheduling pharmaceutical quality control tests: a case study
Monique Sciortino

This study deals with an optimization problem which appears in the context of scheduling quality control tests within a pharmaceutical company in Malta. Scheduling such tests, which are mandatory to approve the safety, purity and efficacy of pharmaceutical product families, is a very challenging task given the limited resource availability and the fact that a single product family must undergo multiple tests. Each week the company needs to plan laboratory tests for approximately 40 different product families, with each family requiring at least 5 different tests. Effective plans are thus essential for increasing efficiency of the laboratory and improving utilization of resources (employees/machines). The aim of this study is to develop an original mixed integer linear programming model for scheduling these laboratory tests at the company. The proposed model has been implemented in GAMS and solved by GUROBI via a Branch-and-Cut solution approach that incorporates various classes of cutting planes. The model determines a schedule over a given planning horizon by minimizing the makespan. It encompasses constraints such as assignment constraints of different stages of tests to resources and timing constraints between tests pertaining to the same product family. Computational experiments were run on real data provided by the company over different planning horizons. The success of obtained results is reported.

4 - Pipeline Scheduling Systems: A novel MILP holistic model
Susana Relvas, Hossein Mostafaei, Pedro Castro, Iiro Harjunkoski

This work deals with an important operations research problem for the petroleum industry. It addresses the scheduling of a multiproduct pipeline featuring multiple input and output nodes, through a novel mixed integer linear programming (MILP). The model uses a continuous-time formulation and is developed in a detailed and rigorous manner. The main novelty concerns consideration of an holistic model that is able to : i) avoid forbidden product sequences in any pipeline segment, ii) consider filler batch constraints to avoid large contamination volumes; and iii) include inventory management constraints in the different pipeline nodes. The model is tested with a motivating example and validated with real size instances from the literature. Apart from resolving the modeling aspects related with the creation of empty batches for downstream input operations, the proposed model exhibits a tight LP-relaxation formulation while being computationally efficient.

■ WA-16

Wednesday, 8:30-10:00 - Theatre A

Mixed-Integer Programming and Applications

Stream: Combinatorial Optimization II
Invited session
Chair: *Monique Guignard-Spielberg*

1 - Cross-dock Scheduling with Known Shipment Unloading Order
Brigitte Jaumard, Thuy Vu, Wael Nassief

We study the cross-dock inbound/outbound scheduling problem that minimizes the number of tardy products. We consider two extensions: (1) Multiple transfer trip shipment, where each shipment requires several trips in order that all the products of it be unloaded, transferred and loaded into its designated outgoing truck, and (2) Known goods/products unloading order, where the unloading order of products inside the incoming trucks is known. These extensions allow an exact computation of the minimum number of tardy products, while the state of the art only computes an overestimation of it. We introduce a time-indexed formulation, with enhanced preprocessing, for the basic and extended cases. We compare our formulation with the best existing one, and provide computational experiments, with optimal solutions, using benchmark instances from the postal and retail industries, with up to 80 trucks and 20 doors. Extensive analyses are provided to demonstrate the economical impact of our proposed extensions.

2 - Strong bounds from RLT and Lagrangean decomposition for pure quadratic 0-1 problems with linear constraints
Monique Guignard-Spielberg

Applying decomposable Lagrangean relaxation or Lagrangean decomposition to RLT1-like models and solving the subproblems as pure 0-1 problems may yield stronger bounds than standard RLT1 bounds for some quadratic 0-1 problems with linear constraints. We present numerical results for several problems of this type.

3 - Computing strong RLT1 Lagrangean Relaxation bounds for quadratic 0-1 problems using the Surrogate Lagrangean Relaxation Method
Jongwoo Park

This talk will present an algorithm for computing Lagrangean Relaxation (LR) bounds after applying RLT1 to some 0-1 quadratic models with linear constraints. The Surrogate LR method was chosen for updating the Lagrangean multipliers. It focuses on obtaining directions that form acute angles toward the optimal multipliers without fully optimizing the relaxed problem at every iteration, thus saving a lot of time. The model obtained after applying the Integer Linearization Property (ILP) to the LR model separates into independent linear subproblems. We obtain the surrogate direction by optimizing only some of the subproblems and take full advantage of the fact that the subproblems are independent. We save the solutions of the subproblems that are fully optimized and use them to partially optimize subproblems in the following iterations. For the models tested, we obtain strong bounds for both small and large instances.

4 - Restrict-and-fix: a constructive heuristic for mixed-integer programs
Cédric Joncour, Julien Kritter, Sophie Michel, Xavier Schepler

We consider a constructive heuristic for mixed-integer pro-grams, that we call "restrict-and-fix". Restrict-and-fix requires a solver able to tackle a sequence of easier mixed-integer programs, denoted as subproblems, which are mainly obtained through constraint relaxations in the original mixed-integer program to solve. These constraint relaxations involve integrality relaxation of some variables, but also combinatorial relaxation of constraints, in order to decompose the original formulation. The solution to each sub-problem allows to fix a subset of the variables in the original mixed integer program as well as in the subsequent sub-problems. This heuristic is a generalization of the relax-and-fix heuristic. We propose an open source implementation of the restrict-and-fix heuristic. We will present this heuristic as well as numerical results with several formulations from the operational research literature, such as those of the bin packing problem, the capacitated multi-item lot sizing problem, the vehicle routing problem. The results show that the ability of the heuristic to efficiently address a formulation depends on its structure and on the definition of the subproblem sequence.

■ WA-17

Wednesday, 8:30-10:00 - A005

Long-term planning in energy systems

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: Irena Milstein

1 - Long-term electricity production planning of a flexible biogas plant considering wear and tear
Hendrik Butemann, Katja Schimmelpfeng

The German Renewable Energy Resources Act 2012 provides incentives for running biogas plants in a flexible way, i.e., producing electricity in times of high prices and storing biogas during times of low prices. Permanent starts and stops of the combined heat and power unit (CHP), however, lead to excessive and irregular wear and tear. Conventional maintenance schedules just take the CHP's operating hours into account, thus implying constant wear and tear. Therefore, their use is not appropriate for a flexibly operated plant. Applying such an inappropriate maintenance strategy might lead to a lower availability of the plant and lost revenues. To overcome this gap, we introduce the Long-term Electricity Production Planning Problem (LEPPP) that determines both the long-term strategy for electricity production and the optimal dates for scheduled maintenance activities simultaneously. Furthermore, we present the numerical results of a case study using data of an existing biogas plant.

2 - Conceptual proposal for a Generation-Transmission Combinatorial Auction in Brazil: Metaheuristic Approach
Fernanda Nakano Kazama, Laura Silva Granada, Paulo Correia

The Brazilian Electricity Sector utilizes auctions as the main way to contract energy and transmission lines. The winners of these auctions are the participants who offer the lowest tariff, aiming at economic efficiency in the contracting. It is crucial that the auctioning system be carefully designed and implemented, because even minor distortions, can have major long-term impacts. A serious problem that has disrupted the start-up of some plants is the unavailability of transmission lines to drain their energy. Once the electricity sector is de-verticalized, the lack of coordination between the construction of new power generation assets and new transmission lines results in power plants disconnected from the system. It is estimated a loss of around 8 billion reais (about 2,25 billion dollars) between 2009 and 2013, since the government was obliged to remunerate the owner of the plant even if there was no actual delivery of energy, unnecessarily raising the cost of energy and affecting the security of energy supply. In this context, this research aims to propose a combinatorial auction of new power generation assets and transmission lines in order to avoid the problem of system disconnection. In this model, both concessions would be bid simultaneously, avoiding the mismatch between them. As the computational time to solve this problem with exact methods can be very high depending on the number of assets auctioned, it is intended to solve the problem using metaheuristic.

3 - A Multicriteria Modelling to the Long Term Generation Expansion Planning considering Greenhouse Gas Emissions
Thatiana Justino, Albert Melo, Nelson Maculan, Maria Elvira Maceira

Worldwide, there is an increasing concern about global warming - or climate change, and the impacts of rising greenhouse gas (GHG) emissions levels in climate systems. Considering that the benefits of GHG emissions mitigation actions are closely related to long term strategies like expansion planning, it would be interesting that the methodologies and models for the Long Term Generation Expansion Planning (LGEP) become promoters of actions to mitigate climate change. This work presents a LGEP model based on multicriteria decision aiding methods, especially suitable for large interconnected and hydro-dominated power systems, such as the Brazilian system, that aims to consider, explicitly in decision making, GHGs emissions. This model will lead to the achievement of compromise solutions among multiple criteria, including climate change (greenhouse gas emissions), energy security (energy deficit risk) and economics (investment and operation costs). The proposed approach encompasses two relevant characteristics of power systems planning: the formulation of expansion plan alternatives and the evaluation of the performance of these alternatives. These steps are carried out through the integrated use of specialized expansion and operation planning models. After, from a multicriteria analysis, the "best" expansion plan is selected according to the preferences of a decision maker. This analysis can be performed by a synthesizing criterion or an outranking method.

4 - Optimal capacity, production and prices in competitive electricity markets when the effective use of PV varies over the day
Irena Milstein, Asher Tishler

This study derives the optimal capacity, and the hourly electricity production and price in competitive electricity markets with substantial capacity of PV that, naturally, can be used to produce electricity only during the day hours (when the sun is shining). Accounting for the demand uncertainty and the large variation of the effective use (usability) of the PV capacity during different hours of the day is at the focus of our two-stage model, which employs PV and natural gas technologies during the day hours, and natural gas technology during the night hours. In the first (construction) stage, firms decide on their generating capacity. The second stage is quantity and price determination. We show that the PV technology produces electricity at full capacity during the early morning and late afternoon hours, and at less than full capacity during mid-day when the sun radiation is at its maximum. Natural gas technology is used during the night and, occasionally, during the day hours when the PV technology is at full capacity and even when the PV technology is at less than full capacity. The main role of the natural gas technology during the day is to reduce the long term PV capacity and avoid large price spikes during the day hours.

■ WA-18

Wednesday, 8:30-10:00 - C112

Recent Perspectives and Advances in Statistics II

Stream: Data Mining and Statistics
Invited session
Chair: *Pakize Taylan*
Chair: *Anna Oganian*
Chair: *Ionut Iacob*

1 - Identifying Drivers of Commercial Value of Healthcare Innovations
Dessi Pachamanova

This talk will discuss a text-based framework for analyzing the commercial value of innovations. Specifically, we show how one can identify key characteristics of patented healthcare innovations that lead to appropriation of value from the patent via licensing. We illustrate the framework using data from a large healthcare provider. Our framework can be useful for organizational forms that not only invest in and commercialize innovations but also act as distributors of intellectual property rights.

2 - Interpretable partial defection prediction - a case study in the B2B parcel logistics industry
Andreas Faber, Stefan Spinler

Churn prediction is an important field in customer relationship management as attracting new customers is much more expensive than retaining existing ones. In B2B markets, churn prevention is of high interest for two reasons. First, competition is high, and customers can easily switch to another provider. Second, the demand of B2B customers often account for a significant share of the total revenue of a company. Thus, it is important to retain customers to not lose significant revenue and profit which is highly difficult due to the competition. Unfortunately, existing research in B2B churn prediction is still scarce. We add to this field with our study of partial defection in a contractual setting where transaction volumes are not fixed. We aim to optimize the financial return from retention actions by comparing classification to identify partial defectors with regression to predict the loss in demand and a combination of both. In addition, we analyze the relation between forecast accuracy and defection definitions. We test different threshold levels to classify customers as partial defectors or not and different lead times between the time of the prediction and the prediction period. The results allow to choose a definition that combines predictive performance with business requirements. We further present a resampling approach to interpret any learning model. Thereby, one can identify the customer specific reasons to partially defect and plan retention actions accordingly.

3 - Clustering of variables to reduce complexity of disclosure limitation methods
Anna Oganian, Ionut Iacob, Goran Lesaja

Statistical Disclosure Limitation (SDL) aims to protect privacy of data subjects in published data sets or data analysis results. Achieving this goal may adversely affect the quality of the published data, especially if it is a big data set with many variables of different types because data protector needs to account for the relationships between the variables. Ideally, SDL methods should not be univariate, but multivariate, handling many variables at the same time. In practice, multivariate SDL is difficult. Its complexity rapidly increases with the data dimensionality. In this presentation we discuss how different clustering techniques can serve as pre-masking data processing procedure to reduce the complexity of SDL methods while maintaining reasonable level of data utility.

■ WA-19

Wednesday, 8:30-10:00 - C115

Portfolio Optimization II

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: *Javier Giner*
Chair: *Babar Syed*

1 - An Omega with entropy model
Shih-Meng Chen, Jing-Rung Yu, Wan-Jiun Chiou, Chen Chang

How to construct an investing portfolio with considering extreme uncertainty in asset returns is a critical issue to finance sector after several financial crises. In this study, we advance Kapsos et al., (2014) Omega model by integrating the entropy approach proposed by Yager (1995). The Omega model considers the upside profit and downside loss by defining a return threshold to simulate the portfolio selection. Other than its flexibility in determining the target return, the Omega model is suitable to a wide-range of assets as it can be reformulated as a linear programming problem. However, the Omega portfolio may overweight the stocks of low price because of their large fluctuation in returns, leading to poor out-of-the-sample performance. Our advanced model synthesizes the superiority in selecting assets of Omega model and the risk control of entropy method. To evaluate the effectiveness of the proposed model, we present the results of the MV model with Yager entropy and the CVaR model with Yager entropy for comparison. To ensure the practicality of the models, we incorporate transaction costs and short selling in the empirical test. The results using the data of the Exchange Traded Funds and the composite stocks in S&P 500 from 2008 to 2009 show our Omega-Yager entropy model effectively reduce the investment risk and decrease the loss during the subprime mortgage crisis. The benefit comes from the diversification responds to market fluctuations in a timely manner.

2 - Alternative portfolio models for Robo-advisor
Chin-Lan Chiang, Jing-Rung Yu, Wan-Jiun Chiou, Hsuan-Hung Liu

Robo-advisor represents one of significant applications in FinTech and can be applied to enhance efficiency in asset management. Most existing robo-advisor frameworks formulate asset allocation by using Markowitz (1952) mean-variance (MV) approach. This implies the decisions are made by utility-maximization investors in an efficient market. The effectiveness of these risk-return approaches is challenged by the theoretical foundations and empirical results due to asymmetric return distribution, fat tail, risk clustering, and poor predictability of asset returns in the real world, leading in general poor out-of-the-sample performance. In addition, the models that apply quadric programming are not suitable to managing a portfolio with a large scale of assets. We advance two distribution-free portfolio models, conditional value at risk (CVaR) model and Omega model, by linearizing the programming problems to incorporate the loss-return preferences of the investors. To ensure practicality, our models include the transaction costs and asset short sales in optimization. We test the realized effectiveness of the MV, CVaR and Omega portfolio models by using the data of the Exchange Traded Funds (ETF) selected by Acorns, Betterment, and Wealthfront during 2012-2018. The empirical results show that using Omega and CVaR models yield higher performance that the MV model.

3 - Dynamic Portfolio Management Strategies Using MV-GARCHs and RiskMetric Methods
Ling Xiao, Gurjeet Dhesi, Babar Syed, Muhammad Bilal Shakeel

To address the time-variant feature of the correlation between portfolio assets, this paper applies the multivariate-GARCH and RiskMetrics methods into portfolio management. Using our constructed international portfolio, it showed that the portfolio strategy based on the MV-GARCHs The results show that the dynamic strategies enable investors to achieve better portfolio performance, and DCC improves upon RiskMetrics strategy.

4 - Trend Following with Momentum Versus Moving Average: A Tale of Differences
Javier Giner, Valeriy Zakamulin

Despite the ever-growing interest in trend following and a series of publications in academic journals, there is still a great shortage of theoretical results on the properties of trend following rules. Our paper fills this gap by comparing and contrasting the two most popular trend following rules, the Momentum (MOM) and Moving Average (MA) rules, from a theoretical perspective. Our approach is based on the return-based formulation of trading rules and modelling the price trends by an autoregressive return process. We provide theoretical results on the similarity between various trend following rules and the forecast accuracy of trading rules.

Our results show that the similarity between the MOM and MA rules is rather high and increases with increasing trend strength. However, as compared to the MOM rule, the MA rules have a more robust forecast accuracy of the future direction of price trends. As a result, under uncertain market dynamics, the MA rules tend to gain an advantage over the MOM rule. Overall, the results reported in this paper help traders to understand more deeply the properties of trend following rules as well as the differences and similarities between them.

■ WA-20

Wednesday, 8:30-10:00 - C006

Emerging Research on Education, Labor Markets and Transversal Competences

Stream: Emerging Research on Education, Labor Markets and Transversal Competences
Invited session
Chair: *Magdalena Graczyk-Kucharska*
Chair: *Małgorzata Spychała*

1 - Modeling Problems in a Regional Labor Market in Poland with MARS
Magdalena Graczyk-Kucharska, Maciej Szafranski, Selma Gütmen, Alper Çevik, Gerhard-Wilhelm Weber, Zbigniew Włodarczak, Marek Goliński, Ayse Özmen

The high dynamics of changes in economies and the related development of new models concerning the functioning of enterprises (Industry 4.0, smart factory, etc.) cause frequent changes in the demand for skills on the labor market. Common (soft) skills have become particularly important. It is necessary to develop methods to analyze the relationship between these skills and other factors affecting them. The analysis and decision problems that are presented in this article are the questions whether and how general skills (O), professional skills (Z) and further economic conditions affect the development of common (soft) skills (W). The three research problems in this article are: 1. how to use big data for supporting and solving analysis and decision making problems; 2. representing a mismatch of competences on the labor market for the needs of employers and government decision makers; 3. preparation of a model as the basis of simulations with the purpose of finding out how the skills, and eventually the qualifications, can become supported for better education and for better accommodating the needs of the labor market. The aim is to design a methodology for supporting the aforementioned analysis and decision making problems. In our studies, we created both (i) a General Model, and (ii) a Reduced (Simplified) Model. In this paper, we briefly address the General Model while the Reduced Model is mostly referred to in our examples and applications.

2 - A large group causal mapping by the aid of 635 nominal group work
Jukka Tikkanen

In this study we present a new hybrid-method for the large group Cognitive Mapping. The method applies 635 nominal group work and the contextual content cognitive mapping (3CM). 635 is a group creativity technique for generating lots of ideas in a short time. First, all members in a group of 6 write down 3 responses on the task given to the group. After 5 minutes, note-sheets are moved to the next group member who complements given ideas. Altogether papers are circulated 5 times until all 6 participants have responded to all original ideas. We applied an e-learning environment for the task. Directed relations between concepts were constructed following three different procedures: In the first version a connection was assumed from the previous concept to the next one in columns of note-sheets; in the second version we asked explicitly what was the tail concept for the given idea; and in the third version respondents also explained the rationale of the connection. The mixed method analysis procedure results in asymmetric proximity matrices, which were then visualised and analysed by the aid of Decision Explorer software. Results can serve a cost-effective and sound starting-point for collaborative learning in the following workshops. Three versions of the procedure are demonstrated and evaluated in real-life examples relating to bioeconomy education.

3 - Mapping public perceptions of universities of higher education in India: A Behavioural OR approach
Jinal Parikh

According to a recent report published by EY, India has remarkably transformed its educational landscape with one in four graduates in the world being a product of her system. India is also among top 5 countries globally in cited research output, with 23 universities in global top 200. The Government of India (GoI) has undertaken massive structural and systemic changes in higher education like reforms in governance, intensive use of technology, transition to a student-centric paradigm of education, expansion of access and qualitative improvement. Despite these efforts by the GoI, India's GER is much lower (16%) than the world average of (27%) in addition to many Indian students choosing to study abroad . Given this background, the purpose of this paper is: 1) to explore the factors influencing public perceptions of Universities of Higher Education in India b) to provide a novel behavioural operational research approach for assessing the relative input-output efficiency of Universities of Higher education in India using Data Envelopment Analysis (DEA) and quantile regression based on perceptions and c) to compare and contrast the results obtained through DEA and quantile regression.

■ WA-21

Wednesday, 8:30-10:00 - F101

Lot Sizing II - Stochastic lot-sizing and inventory management

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: Fernando Paredes

1 - Joint Ordering-Pricing Strategies for a Multi-generation Product Line
Nishika Bhatia, Nalan Gulpinar, Nursen Aydin

Due to rapid advances in technology and design, firms periodically release new generations of electronic products such as mobile phones and computers. In order to increase product variability, firms may develop a multi-generation product line rather than replace the older versions with new ones. However, when different generations of the product are available in the market, they compete with each other as well as other products in the market. Firms need to take joint decisions for the purpose of inventory management and dynamic pricing of multi generations to tackle impact of uncertain demand and market competition. In this paper, we present a dynamic joint inventory-pricing decision model for a firm selling multi generations of a product under uncertainty. We introduce an efficient solution methodology for the stochastic dynamic program and design numerical experiments to present performance of joint inventory-pricing strategies.

2 - A linearization approach to the stochastic dynamic capacitated lotsizing problem with sequence-dependent changeovers
Niels De Smet, Stefan Minner, El-Houssaine Aghezzaf, Bram Desmet

Inspired by the production and planning process of coreboard of our industry partner, a Fortune 1000 player in packaging, we present a mixed-integer linear programming model that can jointly optimize lot sizes, production sequences and safety stocks in the presence of sequence-dependent changeovers. First, we formulate a non-linear (MINLP) model that can handle both the stochasticity and the sequence-dependency of the stochastic dynamic capacitated lotsizing problem, based on the stochastic sequence-independent (Tempelmeier et al. 2018) and deterministic sequence-dependent (Guimaraes et al. 2014) version of the problem. Then, we develop a piecewise linearization approach for the non-linear inventory on hand and backorder curves that builds on and challenges earlier research published by van Pelt and Fransoo 2018 and Tempelmeier et al. 2018. We use the derivatives of the inventory on hand and backorder functions to develop a tailored breakpoint selection strategy that reduces the maximum approximation error between the linearized and non-linear objective function from 20.3% to 0.5% in comparison to the equidistant linearization strategy recommend by the aforementioned articles. As a third and last contribution, we develop a Relax-and-Fix with Fix-and-Optimize heuristic and show in an extensive numerical study that it improved the objective value by 20% on average and realized an average run time reduction of 60% over a state-of-the-art solver.

3 - Mutli-stage stochastic capacitated lot sizing with tight service constraints and robustness considerations
Fabian Friese

This work focusses on the single-level, multi-product dynamic lot sizing problem subject to capacity constraints with stochastic demand. Backlogs are controlled by service constraints. To limit system nervousness, the cost function considers additional costs for short-term changes of the production plan.

A responsive multi-stage planning approach in rolling horizons is introduced, where decisions regarding the production plan for each period are taken in two steps: The setup pattern is determined some periods in advance based on the distribution parameters of demand. The actual production quantities, however, are not fixed until the respective period, factoring in previous demand observations in the final decision. An adjustment of the setup pattern is only made, if the resulting reduction of total costs outweighs the additional costs of induced system nervousness. Therefore, optimal dynamic implicit safety stocks are determined, that ensure high delivery reliability and low total costs at the same time.

To ensure feasibility, unlimited overtime as well as demand realization at the beginning of the respective period is assumed in the first place. However, those assumptions are relaxed in the further course by applying concepts of robust optimization. First numerical experiments have shown, that the proposed algorithm can also be applied to problem settings where realized backlogs cannot be accepted at all, with only a moderate increase in total costs.

4 - Comparison of resolution strategies to solve an optimal inventory management model
Fernando Paredes

In this work we compares resolution strategies to solve a specific optimal management model for a large size inventory, determining the appropriate quantities and safety stocks for a periodic inventory management system, and ensuring that the expected lost sales are minimized for a given level of budget and number of annual replenishment orders. Specifically, the results obtained by solving this non-linear programming model based on a fixed-point solving strategy applied to the Karush-Kuhn-Tucker optimality conditions, are compared with those obtained by the application of Tabu Search and Particle Swarm metaheuristics. The computer results obtained so far are quite promising, when comparing the quality of the solutions found, and their respective solving times.

■ WA-22

Wednesday, 8:30-10:00 - F102

Multi-Objective Analysis in Sustainable Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Karsten Kieckhäfer

1 - Coupling economic and environmental models for decision support in a circular economy
Adrian Werner, Vibeke S Noersteboe, Kyrre Sundseth, Kjetil Midthun

The circular economy paradigm aims at decoupling economic growth from resource use. Transitioning from linear to circular economy practices and using resources more efficiently can reduce negative environmental impacts and generate more value. Hence, "going circular" drives innovation in product and process design, logistics, business models etc. Circularity in itself does not guarantee environmental or social sustainability. Also ensuring short- and long-term profitability represents a barrier to successfully introducing circular business models. Restructured value chains and value networks, closer links between entities in the value chain, new actors and market models, new trade flow patterns indicate a growing necessity to handle dynamics and wider system perspectives. Then, consistent and holistic quantitative tools are crucial to explore effects, to show up potentials and to help businesses to achieve sustainability on many levels. We describe a concept to couple methodology from areas such as techno-economic, socio-economic and environmental analysis. It comprises approaches from, e.g., operations research, macroeconomics and life cycle analysis. Such a holistic framework can aid the analysis of emerging circular economy business models, services or value chain structures with respect to flexibility, profitability and sustainability aspects.

2 - Design and planning of supply chain by monetizing environmental impacts accounting for risk measures
Cátia da Silva, Ana Barbosa-Póvoa, Ana Carvalho

Considering the current need to respond to legal obligations and competitive market pressures, it is necessary not only to work for obtaining good financial results but also to respond to environmental and social practices that are necessary for proper sustainable development. For this reason, in an uncertain market context, decisions involved in supply chain management are complex and there is the need for developing decision support tools to help the decision-making process facing this new supply chain goals. This paper presents a mixed integer linear programming model (MILP) that accounts for the economic and environmental concerns in the same objective function by monetizing environmental impacts while considering risk management through the conditional value-at-risk as a risk measure. The aim is to maximize the difference between economic and environmental performances while simultaneously minimizing the associated risk. The augmented ϵ-constraint method is used to generate a Pareto-optimal curve so as to determine the trade-offs between these two objectives. This work contributes to study the risk associated with both economic and environmental performances while designing and planning supply chains towards green supply chains. A case study is explored.

3 - Sustainable supply chain design under consideration of spatially differentiated ecological, economic, and social impacts
Karsten Kieckhäfer, Christian Thies, Thomas Spengler

Supply chains of high-technology products, such as lithium-ion batteries for mobile and stationary energy storage applications, are often characterized by globally dispersed activities with ecological, economic, and social impacts. As a consequence, companies are increasingly concerned with the sustainability of their supply chains and the design of sustainable supply chains is receiving growing attention. In view of the global extent of supply chains, decisions on their sustainable design must take into account that technologies, environment, markets and society in individual regions sometimes differ significantly, which is why a spatially differentiated view is necessary. We therefore propose an optimization approach for the design of sustainable supply chains under consideration of spatially differentiated ecological, economic, and social impacts. The approach comprises a resource flow model that links production processes to specific locations, multi-scale impact assessment to derive regional and global sustainability indicators, and multi-criteria evaluation balancing the preferences of different stakeholders. In an illustrative example the model is applied to a case study for lithium-ion batteries in order to investigate the influence of regional characteristics and tradeoffs between local and global sustainability measures on the supply chain design.

4 - A MCDA framework for assessing strategic and environmental impacts of electric commercial vehicle implementation
Michael Bruhn Barfod

Urban freight and commercial vehicles make up about 10% of the share of vehicle-kilometer travelled, but account for approx. 50% of the COX and 90% of the NOX and PM emissions. The stress imposed by this on urban systems is expected to increase, due to the fast growth of commercial vehicle activity. A possible technology-oriented solution is electric commercial vehicles (ECVs) that, along with improvements in vehicle routing efficiency, can lead to mitigating the effect of commercial vehicles in urban areas without radical activity reduction. This paper presents the identification and development of a set of KPIs based on user needs for urban mobility and the aim to promote more sustainable transport solutions. This is done in collaboration with a Danish company that has agreed to test whether an ECV solution can meet the requirements of the commercial sector. The company has a number of workers that service building sites and provide maintenance services within the city of Copenhagen, Denmark, and as a part of the study the company has replaced a portion of their fleet to use ECVs. The project aims at uncovering if optimized planning of the service tasks can overcome the shortcomings of the battery range, and thus result in a greener profile without extra costs. A multi-criteria based model is in this context developed to assess both the environmental as well as strategic impacts of the ECVs performance compared to conventional vehicles undertaking the same type of tasks.

■ WA-23
Wednesday, 8:30-10:00 - F103

New Challenges in Investments Strategies

Stream: New Challenges in Investment Strategies, Risk and Financial Modelling
Invited session
Chair: *Mario Maggi*

1 - A fused lasso approach in multi-period mean variance portfolio selection
Valentina De Simone, Stefania Corsaro, Zelda Marino

In this work we describe a fused lasso approach for the regularized multi-period mean variance model, in a Markowitz framework. Since new information is available in a long-period investment, a set of rebalancing dates is introduced, so that decisions are periodically changed by the end of the investment. It is well known that l1-regularization encourages sparsity, since it drives the number of null coefficients. In this talk we propose a new model where two l1-terms are added to the objective function of the arising optimization problem. The first term encourages sparsity on portfolio weights, controlling the holding costs during the investment, while the second corresponds to a further smoothness requirement that allows one to reduce the transaction costs. Indeed, the second l1-term, introducing sparsity in the differences between the weights, can be interpreted as a penalization on the portfolio turnover, thus it limits the number of transactions by preserving the pattern of active position. The problem can be formulated as a constrained nonlinear optimization one, where nonseparability and nonsmoothness of the objective function make the solution computationally demanding. We apply Split Bregman iteration, that is widely recognized as an effective method for this kind of problems. Numerical experiments using real data sets show the effectiveness of the proposed method.

2 - Network approaches based on performance and dependence structure for portfolio allocation
Asmerilda Hitaj, Rosanna Grassi, Gian Paolo Clemente, Paolo Bartesaghi

Modern portfolio theory, Markowitz 1952, allocates the wealth across a set of assets considering only the first and second moments. Despite the profound changes derived from this publication, the out-of-sample performance of this model is often not as promising as expected, due to the large estimation errors on the mean and covariance matrix. We tackle the asset allocation problem considering our portfolio as a network. Under a different perspective, we propose an optimization problem based on a network structure. In the financial literature several methods aim at identifying a portfolio of stocks, with a given cardinality, directly from the dependency structure provided by the financial filtered networks. The authors in Clemente et al. (2019) constructed the market network proposing three different dependence structures (correlation, tail dependence and Kendall correlation). In this paper we move one step further and incorporate a measure of performance, such as assets returns, in constructing the market network. Moreover the effect of the estimation procedure for moments and comoments will be also analysed. In order to validate our models we perform empirical analysis where portfolios obtained through network structures are compared with their analogue mean-variance and equally weighted models. As a robustness check, the proposed approach is applied using empirical data of three different high dimensional portfolios and by testing alternative rolling windows.

3 - Some Formulas for the Bivariate Tail Conditional Expectation in Financial Markets Scenarios
Arsen Palestini, Roy Cerqueti

Tail Conditional Expectation and Expected Shortfall are strictly connected with risk measures, hence they are key tools in the assessment of financial assets in complex markets. We provide and explain some techniques for the explicit calculation of such conditional expectations in the bivariate case, when the related distributions are Gaussian, Student-t or Elliptical. Possible future extensions are also proposed.

4 - Lifetime Investment with Annuities, Housing and Reverse Mortgages
Chul Jang, Iqbal Owadally, Andrew Clare, Muhammad Kashif

We solve the life-cycle investment and consumption problem for an investor who holds cash, stocks, bonds, annuities (immediate and deferred) and residential housing. The investor can purchase residential housing using a mortgage (home loan) and can buy a reverse mortgage (equity release) product after retirement. The investor's risk preferences are represented by standard power utility derived from consumption, both before and after retirement, and from bequest at death. The asset universe is governed by a vector autoregressive model incorporating the Nelson-Siegel term structure, equity return and property return, while the investor's lifetime is governed by an actuarial life table. We use multi-stage stochastic programming to solve the optimization problem numerically. Transaction costs, taxes and management fees are explicitly included. Our numerical results show that deferred annuity purchases are made continuously over the working lifetime of the investor, increasing particularly in the years before retirement. The investment strategy hedges price changes in deferred annuities, and bond holding and deferred annuity purchases increase when interest rates are higher. Additional results on property investment, mortgages and reverse mortgages are pending. Our research shows the potential benefits from the availability of deferred annuities and reverse mortgages, and therefore presents a challenge to the industry to make such contracts widely available.

■ WA-24

Wednesday, 8:30-10:00 - F103A

Inventory models in B2B

Stream: Supply Chain Management
Invited session
Chair: Ton de Kok

1 - Modelling spare parts inventory systems
Ton de Kok

In this presentation we discuss alternative modelling approaches for spare parts inventory systems. Since the seminal METRIC paper of Sherbrooke, spare parts inventory systems modelling is dominated by the Poisson demand assumption. In many situations this is empirically justified, while in other situations this may not be the case. In case it is justified, the Poisson demand assumption also implies independent demand in different time intervals. This allows for modelling spare parts demand as i.i.d. in discrete time. Following this modelling approach, we can apply multi-item multi-echelon systems models derived from the seminal Clark and Scarf paper. We compare the results under the two different modelling approaches and discuss their pros and cons.

2 - Stock rationing in an M/E_k/1 make-to-stock system with limited-patience spot customers
Weina Ma, Chiel van Oosterom, Rommert Dekker

Motivated by an aerospace service provider, we consider a make-to-stock company's stock rationing and ordering decisions. We take into account real-time information on replenishment orders and the number of waiting customers from different classes. The company faces two customer classes: (1) contract customers whose demands are practically always accepted and fulfilled, and (2) spot customers who are rejected, satisfied, or put on a waiting list. The spot customers put on the list may also leave if they have waited too long. We model the problem as an infinite-horizon Markov decision process. States comprise the inventory level, the status of replenishment orders, and the number of spot customers on the waiting list. The first two state variables are aggregated by a variable referred to as work storage level. The objective is to minimize the total expected discounted cost. Our numerical study suggests the optimal policy can be characterized by a sequence of monotone critical work storage levels, which are dependent on the number of waiting spot customers. We also find that two policies which take into account either the option of letting spot customers wait or real-time information on replenishment orders, perform well.

3 - Spare parts inventory control under a fixed-term contract with a long-down constraint
Douniel Lamghari-Idrissi

After the sale of a capital good, the OEM typically provides the option to maintain the capital good in exchange for a certain fee. Performance measures tend to focus on probabilities of fulfilling demand. The customer needs to know the maximum waiting time in order to organize some contingency like buffer stock. For such situation, the customer needs to have a certain guarantee that when the system is down, it will be up and running again within a predefined time. We introduce a new performance measure that limits the number of deliveries that are later than an agreed threshold during the contract period. We consider a single item, single location stockpoint serving multiple systems where demand is satisfied in an alternative way if the stockpoint is out of stock. Using a finite horizon Markov decision process, we characterize the optimal spare parts inventory policy for meeting the contract at minimum costs. We perform a numerical study to show the performance of the optimal policy in comparison to heuristics commonly used in practice. Our results show that the average optimality gap of those heuristics varies from 6:4% to 175%. The maximum optimality gaps are very high for all three heuristics. This shows that important savings can be made when taking into account the actual contract performance and the remaining contract duration in stocking decisions.

4 - Integrating Supplier Selection and Inventory Management with Imperfect Quality and Supply Disruptions
Thomy Saputro, Bernardo Almada-Lobo, Gonçalo Figueira

Suppliers play a vital role to the success of companies by providing good quality materials with competitive prices, while ensuring on-time delivery. Moreover, in the present global market, managing supply is not straightforward due to uncertainty and disruptions. To mitigate their impact, supplier selection, especially for critical items, should consider subsequent decisions, such as order allocation and inventory management. We approach such setting and take into account uncertain supplier-buyer parameters, particularly incorporating stochastic demand and suppliers' imperfect quality, as well as disruptions in supply. The cost incurred due to imperfect quality is considered, which includes the defect cost per unit purchased and the defect holding cost. Supply disruptions are taken into account since it is the main factor affecting delivery delay. This work proposes a methodology to address this issue based on simulation-optimization. Supplier selection is determined by a genetic algorithm, while inventory decisions are computed with analytical expressions. A discrete-event simulation model is used to evaluate the overall performance, considering demand and quality uncertainty, and supply disruptions. The impact of different parameters, such as imperfect quality, lead-time and disruptions, is analyzed. This analysis should help to provide managerial insights on supply decisions.

■ WA-25

Wednesday, 8:30-10:00 - F104

Production Systems

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: Fabian Wilschewski

1 - Evaluation of Unreliable Flow Lines with Spare Parts Provisioning
Florian Sachs, Gudrun Kiesmuller, Stefan Helber

We consider an unreliable flow line with interstage buffers where downtimes of the machines are induced by the failure of critical machine-components. Each machine is assumed to have exactly one of these failure-prone components. It is known that the buffer decouples adjacent machines and therefore reduces interferences caused by downtimes or stochastic production times. However, installing buffer spaces is costly and will additionally lead to rising work-in-process inventory costs. In order to directly increase the machine-availabilities and thus reduce downtimes we keep spare parts of the components in stock and implement a repair-by-replacement policy. In contrast to the previous research, we are able to analyse systems with an arbitrary number of machines and spare parts provisioning. For this purpose, we derive the necessary equations of a decomposition approach to describe the system behaviour. Therefore, we develop an exact solution for the two-machine problem, whereon the decomposition approach is based. By means of numerical examples, we analyse the impact of different parameter constellations on the quality of the approximation. We can show the excellent performance of our method by comparison of our results with simulated values.

2 - Towards a multilevel control concept to operate modular production systems
Dietmar Neubacher, Nikolaus Furian, Clemens Gutschi

Customization of products and fluctuating markets impose grand challenges for manufacturers. Especially the increase in product variety and consequently manufacturing or assembly variance destabilizes smooth production flows and constant work in progress. In response to these trends, organizations increase the flexibility of their production systems, mainly in terms of routing and processing. These transitions enable several benefits, but also imply grand challenges for production operation, mainly because the emerging complexity in modular and flexible production systems is often beyond control. We will present examples of actual modular production systems and highlight associated problems when using classical production control strategies. Furthermore, we propose a hierarchical control concept to emphasize control structures and to expose accountability and responsibility for individual activities. We demonstrate how this approach enables the required controllability to operate these complex production systems. Using a simulation-based approach, we are able to reproduce critical system states and develop strategies or algorithms to avoid malfunctions. Finally, we propose a multilevel control concept in order to stabilize and operate modular production systems more efficiently.

3 - A Row Generation Method for the Unrestricted Block Relocation Problem
Fabian Wilschewski, Alf Kimms

One possibility of storing items is to pile them up in stacks. In that case, an item can only be retrieved if it is the topmost item of a stack. Consequently, an item can be blocked by other items stored above it. If an item to be retrieved is blocked, repositioning moves are necessary. Since these repositioning moves can be very time consuming, the objective is to minimize the total number of repositioning moves. In this talk, an introduction to the block relocation problem is given. After a short overview of existing literature an exact solution method is presented.

■ WA-26

Wednesday, 8:30-10:00 - F106

OR and Ethics and Social Complexity III EthOR jury meeting

Stream: OR and Ethics
Invited session
Chair: Pierre Kunsch

1 - Application of the Environmental Education Program and development of environmental awareness in university students
Cesar Teodoro Arriola Prieto

Introduction: Environmental education develops and strengthens an awareness that stimulates respect and coexistence of people towards their natural and cultural environment, knowing adequately the resources and their capacity for sustainable use, achieving the overall wellbeing of the community, immersed is the University who adopts a position on environmental issues and acts in different areas of its competence. Objective: To determine the influence of the application of an environmental education program on the development of environmental awareness in university students. Material and methods: The population was 123 university students, the sample was 60 students through intentional non-probabilistic sampling. The technique used was the survey and the instrument was a questionnaire of own authorship, applied in two prestest and posttest times. The research was quantitative, cross-sectional, applied and pre-experimental design. For the statistical processing the statistical software IBM SPSS was used and statistical results of summary measures, frequencies and percentages were obtained; For the testing of the hypotheses the Student's T-statistic was used for related samples. Ethical aspects considered: respect for the person, privacy, beneficence and informed consent. Conclusions: The application of an environmental education program significantly influences the development of environmental awareness in university students.

■ WA-27

Wednesday, 8:30-10:00 - F107

Network Analytics

Stream: Network Analytics and Optimization
Invited session
Chair: Balázs R. Sziklai

1 - Extended formulations and column generation algorithm for the Virtual Network Functions Placement and Routing Problem (VNFP-RP)
Ahlam Mouaci, Ivana Ljubic, Nancy Perrot, Eric Gourdin

The virtual network function placement and routing Problem is a recent network optimization problem. It consists in determining where to deploy a set of service functions and how to route flows in a network so as to satisfy a set of requests for several services at minimal cost. This telecom problem is of great importance to manage future networks. Indeed, networks are becoming programmable and advanced network functions such as Firewall or load-balancer are being virtualized. This network evolution brings a huge flexibility, but it requires to know how to take both the right function placement and routing decisions simultaneously.The virtual network function placement and routing Problem is composed of two optimization problems: a multicommodity flow problem and a facility location problem, with some additional constraints such as end-to-end latency, incompatibility and precedence between the functions and linking constraints. Taking advantage of the decomposable structure of the problem, we propose two extended formulations and develop for each one a column generation framework to solve it. In the first formulation, the pricing problems consist in generating paths while respecting the latency while in the second extended formulation, the pricers consist in generating paths with installed functions. From numerical experiments these two extended formulations give interesting linear relaxations.

2 - ANGEL - Air Networks Generation Emphasizing Layers
Marzena Fügenschuh, Ralucca Gera

Airline transportation networks develop independently based on the needs of carriers, economic and political factors, as well as their interactions. A deeper study of these networks provides insights into the growing process and the characteristics of multilayer networks in general. We present a novel approach to create synthetic networks based on a hub and spoke structure embedded in a multilayer structure. Our methodology is derived from a profound analysis of the European Air Transportation Network. To analyze the reference network and to validate synthetic models we introduce statistics, which can be applied to study multilayer networks in general. Finally, a generalization of our method to create miscellaneous random multiplexes will be implied.

3 - Minimum-Cardinality Balanced Edge Addition in Polarized Networks
Celso Ribeiro, Ruben Interian

Polarization is the division into sharply contrasting groups or sets of opinions or beliefs. The issue of polarization has been discussed by politicians, media, and researchers. Fake news spread faster in polarized networks or groups. At the same time, fake and tendentious news can accentuate polarization within already existing echo chambers in the social networks. Polarized networks are divided into two or more strongly connected groups, with few edges between vertices belonging to different groups. In order to reduce polarization, networks can be treated by minimal external interventions consisting of the addition or the removal of vertices and edges. A new optimization problem addressing the issue of polarization reduction by edge additions is presented in this work. We formulate the Minimum-Cardinality Balanced Edge Addition Problem. Next, we discuss its complexity and we propose integer programming approaches for its solution.

4 - Opinion leaders - experts of social relations
Balázs R. Sziklai, Balázs Lengyel

Opinion leaders are one of the most important and researched group in social networks. One of the main features of this group is their paramount roles in the diffusion of new products and technologies. Opinion leaders may be viewed as experts in social relations, thus expert selection methods might be applied to identify them. We test the novel method of Sziklai (2018) as well as classical centrality measures to assess the spatial diffusion of social media. For testing a unique dataset of iWiW is considered. iWiW was the most widely used social network in Hungary before the era of Facebook. Over its life-cycle, it had more than 3 million subscribers who engaged in over 300 million friendship ties. As both the address and the time of registration of the users are recorded we can model the diffusion of iWiW as well as those individuals (i.e. the opinion leaders) who played key role in it. This allows as to test which algorithm is the most adequate to identify opinion leaders.

■ WA-28

Wednesday, 8:30-10:00 - G102

Financial Accounting & Auditing

Stream: Operational Research in Financial and Management Accounting
Invited session
Chair: Matthias Amen

1 - Complexity in International Accounting Standards - model based analysis for IFRS 8
Matthias Amen

International Financial Reporting Standards are not written by OR-skilled experts. As the IFRS sometimes have a lot of quantitative requirements, we are often faced with several conditions that should be fulfilled, but that create a system that seems to be too complex for the actual preparers of financial statements. This will be demonstrated on IFRS 8 "operating segments" which defines some requirements for combining operating segments to a smaller set of aggregated reporting segments. The complexity becomes obvious when we formulate the requirements in a model. IFRS 8 provides some way outs for practitioners who just claim that it is "impossible" to follow all of the requirements for their company. With a quantitative model approach, we are also able (a) to prove definitely whether there is a solution for the special instance or not, and (b) to optimize the assignments of operating segments to reporting segments.

2 - The Determinants of Corporate Social Responsibility-Reporting in Critical Perspective: Does a Selection Bias Exist?
Vladlena Prysyazhna, Sascha H. Moells

Companies today are expected not only to maximize their value and provide relevant financial information about the ongoing business, but are also presumed to engage in environmental and social activities as an integral part of their management process. Such activities are typically made transparent towards stakeholders by means of a "corporate social responsibility"-reporting using guidelines such as the GRI-framework. The determinants of such a CSR-disclosure have been analyzed in several empirical studies which in most cases are based on (small) samples of the largest firms from Europe or/and the US. Referring to this feature of previous studies we show that analyzing only the largest companies leads to a selection bias. Addressing this econometric problem our analysis is based on two panels each encompassing the biggest 100 publicly traded corporations of the US and five major European countries. The panels cover the years 2003-2007 as well as 2008-2012 resulting in 6000 firm-year observations. Based on the GRI-framework we, firstly, conduct a detailed content analysis of CSR reports and related firm documents to construct an aggregated index representing the scope of CSR-disclosure. By applying a rarely used method that allows us to capture both the between and the within variation of variables we, secondly, show that the relevance of financial ratios as well as corporate governance attributes for the scope of CSR-disclosure differs across companies of different size.

3 - The Deterrence of Management Fraud: A Dynamic Analysis
Ashutosh Deshmukh, Varun Gupta

Management fraud has been a perennial problem in assessing the integrity of the financial statements and have led to many audit failures. Such routine audit failures negatively impact a firm's operations. The auditors over the years have struggled to refine methods of identification and detection of management fraud. The regulators and policy-making bodies are also aware of the problem and have responded aggressively by increasing the responsibility of the auditors regarding fraud detection. The public accounting faces a crisis of confidence every decade and as a result, stringent laws are routinely passed increasing the auditors' responsibility.

The purpose of this paper is to use an overlapping generations model to analyze the problem. A crucial assumption is when the management fraud is more prevalent in a given eco-system, it is harder to detect and audit such fraud. The overlapping generations model gives rise to many stationary equilibrium levels of fraud. As such a given system may have a low incidence of fraud or a high incidence of fraud equilibrium. A strong measure such as Sarbanes Oxley Act, 2002 may be employed and can give rise to low incidence equilibrium in a given system.

The paper studies the negative impact management fraud has on a firm's operations and also analyzes the consequences of these results for the auditors and policymakers. The paper concludes with some possible extensions of the research and limitations of the research.

4 - Identifying Board of Director Network Influence for Firm Characteristics
Aparna Gupta

We utilize network analysis to evaluate the relationship between firms' characteristics and board of director networks. In a sample of 20 largest firms by market value from the energy and the utility industrials, 10 from each sector, we cluster the firms by their firm-level characteristics, as well as develop a multiplex network of the firms' board members consisting of two major layers, one for board members' direct connections and another for their indirect connections. Additionally, 4 sub-layers of each major layer of the multiplex network represent corporate, non-profit organization, education and government/military connections between the board members. Each layer of the multiplex network is weighted so that their combined effect can be depicted as a single layered directors' network. The weights of the multiplex directors' network are learned by relating a firm's director network characteristics with the firm cluster characteristics. We observe that director networks display significant connectivity at all multiplex network layers and firms belonging to the same cluster display similar director network characteristics, specifically enhanced by appropriate weighting of director network layers. The optimal value of network layer weights are found by optimizing the cohesion of firms in a cluster and the director network multiplex layers.

■ WA-30

Wednesday, 8:30-10:00 - C007

Industrial Optimization

Stream: Data Science Meets Optimization
Invited session
Chair: Grzegorz Pawlak

1 - Symbiotic Simulation System for Industry 4.0
Stephan Onggo, Christine Currie, Thomas Monks

We review the literature on symbiotic simulation research and its applications, where we define a Symbiotic Simulation System to be a simulation system designed to support online short-term operations management decision making. The prevalence of real-time data and the advances in Industry 4.0 technologies have made implementing the vision of using simulation to support real-time decision making a reality. Symbiotic simulation enables a communication between a physical system and the simulation model that represents it as its digital twin in real- or near real- time. From the modelling perspective, a symbiotic simulation system comprises a hybrid systems model that combines simulation, optimization and machine learning models as well as a data acquisition module and an actuator. The actuator is needed when the symbiotic simulation system is designed to directly control the physical system without human intervention. We propose a conceptual architecture of a Symbiotic Simulation System highlighting research questions and challenges to advancing its use in practice.

2 - Exploring Log Data from Automotive Testbeds: An Approach Towards Predictive Decision-Making
Gernot Lechner, Andreas Festl

In the automotive domain, testbeds used, e.g. for engines play a major role for ensuring product quality. Besides product-related measurements, such testbed systems produce additional data describing operating conditions of various testbed components and the automation system. Although being collected, the actual usage of this auxiliary data is often limited to specific tasks, such as determining operative readiness of testbeds based on software status. Rules and conditions for identifying different states are handcrafted by domain experts-a costly, error-prone and time-consuming procedure. Our work aims at automatic extraction of knowledge and insights from this data by applying advanced methods of data analysis and machine learning. For development and validation of our procedures we use a large dataset of about 450 million data points, produced by multiple different testbeds. The dataset is explored in detail to identify patterns that facilitate the prediction of future malfunctions within the testbed system. Therefore, we examine Markov-type models for anomaly detection by describing joint transition probabilities for sub-sequences of suitably encoded log messages. Indeed, we observe a distinct change in this probability several minutes/messages before malfunctions or uncommon events. On top of the Markov base model, we investigate performance of automatic methods for error prediction by utilizing various models from statistics and machine learning.

3 - Comparison of Maintenance Policies for Multi-Component Systems under Simulated Faults
Michele Urbani

The search for optimal maintenance policies for complex multi-component systems is a challenge in industry. This work compares several maintenance policies for complex systems with non-identical components and economic dependencies in case of sudden faults. Discrete event simulation and the Monte Carlo technique replicate fault occurrence, while a genetic algorithm minimizes the cost of maintenance by finding optimal groups of maintenance activities. The variation of the setup costs of the activities is exploited to produce a large amount of data regarding potential costs of maintenance. Furthermore, a multi-criteria analysis harnesses information on the reliability of the system and on the cost of maintenance to compare the results in a graphical way. The expected cost of each policy and their variance are analysed together with worst case scenarios. The behaviour of policies remained steady independently of the variation of the setup cost and the policies with dynamic optimization of the plan in case of fault showed very similar variance of costs; others instead were found very expensive in more than 10% of cases. When decisions are far into the future, the adopted analysis methodology could effectively help in estimating uncertainty about the policy to adopt. Against preventive maintenance policies with and without fault optimization, the opportunistic grouping policy was the most cost effective, robust and reliable.

4 - Logistic Simulation Model for the Supply Car Factory
Grzegorz Pawlak

One of the micro logistic problem in the factory was the internal traffic organization to avoid the bottlenecks from one side and the load balancing and production continuity on the other hand. The analyzed problem was to model the internal lorry traffic with the loading and unloading areas. Moreover, the aim was also to estimate the influence on the external factory car traffic and parking lots. The simulation model was elaborated and several suggested cases evaluated for the real example in the car factory. Representative data of traffic density on the surround roads were collected, analyzed and included into the model. The experiment validated assumptions about the traffic density and organization and found out the potential bottlenecks and the starving stocks in the production processes. The balanced routing model of internal plant traffic organization was suggested and validated. Taking into account the shifts changes and peak traffic generated by the workers accordingly the model was simulated and evaluated. The computational experiment was proposed and several phenomenon was discovered and analyzed. The software tool was developed and used for the experiments for the particular practical cases. Several WHAT IF analysis cases were inspected and conclusions were drown, respectively.

■ WA-31

Wednesday, 8:30-10:00 - G108

Appointment scheduling problems

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: Roberto Aringhieri

1 - Integrated capacity allocation and appointment scheduling for access time management
Ka Yuk Carrie Lin

This paper examines the strategy of integrated dynamic scheduling of service capacity and patient appointments in a multi-server outpatient appointment system with multi-priority patient classes. The integrated approach is compared with a base scenario which schedules appointments to a given set of capacity without adjustment. The system performances are measured by the patient access time to an appointment and the capacity utilization over a multi-day horizon. The service standard is based on proportion of appointments satisfying a target access time by priority class. Data on specialist outpatient clinics in public hospitals are used in simulating test instances with and without seasonality assumptions. Mixed integer goal programming models are formulated and solved as benchmarks for the dynamic solutions. Analytical properties of special cases are derived for proving optimality and developing heuristics. Incorporating regularly updated demand forecasts, access time rules are established with heuristics and simulation for dynamic appointment scheduling.

2 - Master scheduling of ambulatory block times in a cancer outpatient clinic
Elena Tanfani, Giuliana Carello, Paolo Landa, Angela Testi

This paper address the tactical level planning problem of determining the assignment of ambulatory consultation slots in a Cancer Outpatient Clinic. This research is motivated by a collaboration with the San Martino Hospital located in the city of Genova (Italy) recently involved into a reorganization process aimed at setting up a new outpatient cancer center. The center is dedicated to treat oncology and hematology patients of seven specialties who need chemotherapy treatments and outpatient appointments. A preliminary simulation study has been performed to determine, at a strategic decision level, the number of seats and beds available for the chemotherapy treatments, as well as the number of ambulatories dedicated to the clinician consultation. The still open problems are two. At a tactical level, determining the assignment of specialties and clinicians to the available ambulatory slots, based on the clinicians availability and the clinical characteristics of patients in the waiting list of each specialty. At an operational level, determining the appointment scheduling of patients in each day. In this work, we focus on the first problem, proposing a MIP optimization model aimed at levelling the treatment demand of the specialties who compete for the use of the outpatient clinic resources. Preliminary results on the real case study are reported together with a set of instances generated to verify the performance of the model with respect to variation of the input parameters

3 - Flexible shift design and flexible task assignments for medical radiation technicians
Jens Brunner, Jakob Heins, Jan Schoenfelder, Sebastian Kraul

The ongoing workforce shortage and the increasing expenditures in hospitals lead to difficult tasks for hospital management. Especially in personnel scheduling, it is crucial to utilize advanced approaches supported by operations research methodology, because an optimal schedule can increase service quality and reduce overtime as well as wage costs. In this study, we develop a combined flexible shift design and flexible workplace assignment problem that handles workstation rotation requirements. The goal is to find the optimal plan to minimize overtime and the number of medical radiation technicians for a given workforce pool. Due to the complexity of the program, we solve the problem with a column generation heuristic. We use real-world data from a radiology department and schedule medical radiation technicians. We provide insights how this approach can be beneficial for schedules with pre-defined shifts. Furthermore, the effects of allowing or requiring workstation switchovers are discussed and evaluated.

4 - Online algorithms for the radiotherapy patient scheduling problem
Roberto Aringhieri, Davide Duma, Giuseppe Squillace

A radiation therapy consists in the effective clinical use of ionizing radiation for the treatment of malignant tumors. The radiation is delivered by a linear accelerator or linac, which is a special device whose main function is to concentrate in beams and accelerate the emission of subatomic particles. Radiotherapy could be the primary therapy or delivered together with other therapies. A radiotherapy treatment consists in a given number of radiation sessions, one for each (working) day, which should start before a given release date. Patients are usually classified into classes of urgency having different release date and number of sessions.

The Radiotherapy Patient Scheduling (RPS) problem falls into the broader class of multi-appointment scheduling problems in hospital in which patients need to visit sequentially multiple or single resource types in order to receive treatment or be diagnosed. The RPS can be view as a version of the job shop scheduling problem in which a job is a patient, each operation is a session, all the operations must be performed on the same machine (linacs), and the machine assigned to each job is part of the decision process.

After deriving a general problem statement from the case study in the literature, we present online optimization algorithms that tries to exploit the particular structure of the solution, and we compare their results with an online algorithm with look-ahead. Further, we provide an approximated competitive analysis.

■ WA-32

Wednesday, 8:30-10:00 - G109

Sports competitions: problems, algorithms, and fairness

Stream: OR in Sports
Invited session
Chair: Frits Spieksma

1 - RobinX: an XML-driven three-field classification for round-robin sports timetabling
Dries Goossens, David Van Bulck, Mario Guajardo, Jörn Schönberger

In a round-robin timetable, often called a schedule, every team plays against every other team a fixed number of times. Over the past 40 years, the increasing interest in sports timetabling has been accompanied by the introduction of a wide variety of new constraints and objectives. This variety makes it challenging to determine the relevant set of papers for a given timetabling problem. Moreover, the lack of a generally accpeted set of benchmarking problem instances makes it hard to assess algorithm performance. To mitigate these issues, we present RobinX: an XML-driven three-field classification framework that describes round-robin problem instances by means of the competition tournament, the constraints in use, and the objective. To store problem instances and their solutions, RobinX offers different XML-based file templates that follow the structure of the three-field classification. Moreover, we provide a C++ library that can be used to read, write, and validate these files: if a solution respects all hard constraints as specified by the problem instance file, RobinX returns the objective value. Otherwise, RobinX returns a list with all violated hard constraints. To encourage future research, we provide an instance data repository containing over 40 encoded artificial and real-life problems from more than 15 different countries. RobinX is embedded in a user-friendly web application offering researchers the opportunity to query or submit problem instances and solutions.

2 - What algorithms to select in sports timetabling?
David Van Bulck, Dries Goossens

The sports timetabling problem is a combinatorial optimization problem that consists of designing a timetable that defines against whom, when, and where teams play games. Over the years, various algortihms based on integer programming, constraint programming, and metaheuristics have been proposed. Unfortunately, the majority of these algorithms are only tested on one or two seasons of the competition under consideration. Besides, the fact that no single best algorithm works well on all problem instances makes that few algorithmic insights are known. The recent introduction of RobinX, an XML-driven three-field classification framework for round-robin scheduling, offers two major opportunities. First, the associated problem instance repository of RobinX makes it possible to test algorithms on a larger number of instances. Second, RobinX classifies problem instances according to their competition format, constraints in use, and objective function. This makes that problem instances can be described in terms of features. In this talk, we explore how we can exploit these features to provide researchers with promising solution methods when facing new problems. As an example, given that stadium availability is a major concern, should we develop algortihms based on integer programming or based on constraint programming? Moreover, we explore which features make it much more difficult to solve a problem for current state-of-the-art algorithms.

3 - On the multi-league sport scheduling problem
Morteza Davari, Dries Goossens, Jeroen Belien, Frits Spieksma

There has been a lot of recent work on sport tournament scheduling. However, much of the literature has focused on scheduling a single tournament (league). In this work, we consider scheduling multiple leagues, with inter-dependencies arising from teams in different leagues belonging to the same club. This is a common setting for instance in youth competitions, where a club typically has a team for each age category. The teams from the same club share the same venue, which consists of a limited number of terrains. The objective is to minimize the total capacity violation over all clubs during the whole season. We show that the problem can be solved in polynomial time for two special cases: (1) when the league size is even and (2) when the club size (the number of teams in a club) is the same for all clubs and equals the league size.

4 - Fair Competition Structures
Ritxar Arlegi, Dinko Dimitrov

Discussions about the fairness of different types of competition systems are often made at an informal level. We provide a structured analysis of such discussions on the basis of two principles of fairness that respond to the Aristotelian Justice Principle of "treating equals equally and unequals unequally". In our framework, these principles require on the one hand that the competition system should not favor weaker players, and on the other hand that equally strong players should have the same chances of being the final winner.

We apply these axioms to a class of competition structures which includes, as particular cases, round-robin tournaments and different kinds of knockout competitions. We characterize the structures satisfying the two axioms and also specify the type of seeding rules that let the structures satisfy them.

Among other results, we identify a special competition structure, which we call an antler, that turns to be referential in the sense that any playoff structure containing an antler as a substructure may give weaker players greater probabilities of being the final winners. As a matter of fact, it is possible to find major competitions that are antler-free (the US MLB postseason playoffs or stepladders, for example) and others that are not (the US NFL playoffs or any balanced elimination-type competition with more than 4 players). The former suffer from the said drawback while the later do not.

■ WA-33

Wednesday, 8:30-10:00 - Q005

Dynamics and Games II

Stream: Dynamics and Games
Invited session
Chair: Tahl Nowik

1 - Multiple beliefs, multi-stage decisions and dynamic consistency
Tommi Ekholm, Erin Baker

We investigate multi-stage decisions under multiple beliefs, exploring the dynamic consistency of complete and incomplete preference orderings. Special attention is paid to belief dominance: a concept that supports decision-making under multiple probability characterizations by ruling out strategies that are dominated across the full range of beliefs. We uncover a distinction between two types of dynamic inconsistency, which we label fallacious and fallible inconsistency. Fallacious inconsistency occurs when a strategy that was optimal in the first-stage is found to be sub-optimal in a later stage. Fallible inconsistency implies that an action is optimal in the second stage, although that action was not included in any optimal strategy in the first-stage. Fallible inconsistency is less severe, as it doesn't necessitate a rational decision-maker to depart from her original strategy, as fallacious inconsistency does. Using corresponding definitions for dynamic consistency, we show that the two are equivalent for complete orderings, but differ for incomplete orderings, such as dominance relations. Subjective expected utility is dynamically consistent while non-expected utility decision rules, such as minmax, are not. Belief dominance falls between these two: it is immune to the more severe fallacious inconsistency, but not to the less problematic fallible inconsistency. We illustrate the concepts with a focal, real-world problem involving deep uncertainties: climate change.

2 - Search game on three arcs with any starting point
Ljiljana Pavlovic, Milica Milivojevic

We consider a search game for an immobile hider on three arcs of unit length which join two points and the starting point of the searcher is anywhere. We find optimal strategies of the players and the value of restricted game, (the set of pure strategies of the searcher is restricted), which are probably optimal strategies and the value of unrestricted game. This game shows how optimal strategies and the value of the game depend on the starting point.

3 - Network Optimisation in Mining
Doreen Thomas, Marcus Brazil, Joachim Rubinstein, Peter Grossman

Reducing the cost of mining operations is an important issue for mine developers and operators faced with an extremely competitive market place for mineral commodities. In many underground mines, access is provided via a network of interconnected underground tunnels, called declines and drives. The miners and their equipment are transported to the mine face along the declines and drives and then the ore is hauled back to the surface. The declines have to satisfy certain constraints so that the large haulage trucks can navigate them. The problem is to design this network of navigable declines so as to minimise the cost of both constructing the network and hauling the ore. Costs of development and operations in underground mines are so large that even a 100 metre reduction in the length of haulage paths - which may be many kilometres long - can correspond to a $1M saving, when construction, ventilation, maintenance and haulage costs over the life of a mine are taken into account. The team has used mathematical network theory and geometric analysis to develop software tools to optimise mine layouts and these tools, which have been used in mines in Australia, New Zealand and the United States, have now been commercialised. Underpinning this new software is mathematical research which has led to significant advances in the theory of these 3-dimensional navigable networks.

4 - Games with Costly Winnings
Tahl Nowik, Irit Nowik

We introduce a new sequential game, where each player has a limited resource that he needs to spend on increasing the probability of winning each stage, but also on maintaining the assets that he has won in the previous stages. Thus, the players' strategies must take into account that winning at any given stage negatively affects the chances of winning in later stages. Whenever the initial resources of the players are not too small, we present explicit strategies for the players, and show that they are a Nash equilibrium, which is unique in an appropriate sense.

■ WA-34

Wednesday, 8:30-10:00 - Q006

Analytics and Pricing

Stream: Analytics and Pricing
Invited session
Chair: Danny Segev

1 - A Generic Exact Method for the Assortment Problem with Nested-Logit Choice Model
Alborz Hassanzadeh, Laurent Alfandari, Ivana Ljubic

We study Assortment Optimization Problem with Nested-Logit Choice Model. The state-of-the-art for this revenue management problem is a polynomial exact method when dissimilarity parameters between nests are less than one, based on sorting products by revenues and approximation algorithms for the other cases (Davis et al., 2014). We complement these results by providing a generic exact method that applies to the NP-hard case when dissimilarity parameters can take arbitrary values and there are no assumptions on the structure of the nests or the combination and characteristics of products. The exact method is based on fractional programming. At each iteration, a parametrized 0-1 non-linear subproblem is solved by a Branch-and-Bound algorithm with specific bounds adapted to various data scenarios. A key advantage of this approach is that the subproblem can be decomposed by nests into M binary non-linear subproblems. A pre-processing phase reduces the size of each subproblem by identifying those products that are certainly beneficial to offer or not, which reduces computation time. This approach enables us to solve instances with up to 5 nests and 500 products in short computing times. Numerical results show that the expected revenue of the optimal solution can be up to 40% higher than the revenue of the "sorted-by-revenue" heuristic solution when dissimilarity parameters are free. The range of dissimilarity parameters is shown to be critical in the performance of our method

2 - Dynamic bundling and pricing for LTL transport requests in Physical Internet
Bin Qiao, Shenle Pan

This work investigates the dynamic bundling and pricing problem for LTL requests in Physical Internet. From the perspective of carrier, bundling freight transport requests means accepting a package of requests that have synergies on their routes for transport cost reduction. In this work, we consider the situation in which a set of LTL requests with different O-D pairs in a network and carriers should consider request bundling to increase their fill rate and profit. Under combinatorial auction (CA) mechanism, carrier should decide the profitable request bundles that they want to transport and the optimal bidding price to maximize his total profit. Moreover, the future possible requests on the route should also be considered to improve the decision. We propose a mixed integer nonlinear programming (MINLP) model to solve the problem, which optimizes dynamic bundle (route) generation and pricing simultaneously. The model can be used as a decision-making model for carriers to establish real-time transport planning and pricing. A numerical study is constructed to evaluate the feasibility of the proposed model.

3 - Pricing of Reusable Resources under Ambiguous Distributions of Demand and Service Time
Xuan Vinh Doan, Xiao Lei, Siqian Shen

Monopolistic pricing models for revenue management are widely used in practice to set prices of multiple products with uncertain demand arrivals. The literature often assumes deterministic time of serving each demand and that the distribution of uncertainty is fully known. In this paper, we consider a new class of revenue management problems inspired by emerging applications such as cloud computing and city parking, where we dynamically determine prices for multiple products sharing limited resources and aim to maximize the expected revenue over a finite horizon. Random demand of each product arrives in each period, modeled by a function of the arrival time, product type, and price. Unlike the traditional monopolistic pricing, here each demand stays in the system for uncertain time. Both demand and service time follow ambiguous distributions, and we formulate robust deterministic approximation models to construct efficient heuristic fixed-price pricing policies. We conduct numerical studies by testing cloud computing service pricing instances based on data published by the Amazon Web Services (AWS) and demonstrate the efficacy of our approach for managing revenue and risk under various distributions of demand and service time.

4 - Click-Based MNL: Algorithmic Frameworks for Modeling Click Data in Assortment Optimization
Danny Segev, Ali Aouad, Jacob Feldman, Dennis Zhang

This work augments the predictive and prescriptive abilities of traditional choice models in e-commerce settings by incorporating clickstream information, which corresponds to customers' search and click behavior. Our main modeling assumes that clicks coincide with the set of items considered by a customer during a product screening phase preceding her final choice decision. This leads us to introduce a new click-based choice model whose underlying dynamics unfold in two stages. First, the customer forms her consideration set according to the click propensities. Then, she makes a purchasing decision from among the products in this restricted consideration set according to a traditional choice model. Unlike conventional models, we view the consideration set as explicitly defined by the click behavior, rather than being an unobserved latent parameter of the choice-making process.

The random nature of how consideration sets are generated creates computational and probabilistic hurdles that require novel methodological frameworks for the resulting assortment optimization problem. In this context, our main technical contribution is that of devising a slightly super-polynomial-time approximation scheme for the latter problem, thereby approaching optimal expected revenues within any degree of accuracy. From a practical perspective, we establish the predictive power of our click-based choice model using historical click/purchase data obtained in collaboration with Alibaba.

■ WA-35

Wednesday, 8:30-10:00 - Q009

Routing and Prediction in Healthcare Logistics

Stream: Healthcare Logistics
Invited session
Chair: Sibel Salman

1 - Estimating Visit Durations for Scheduling and Routing Optimization in Home Care Applications
Mateusz Polnik, Annalisa Riccardi, Edmondo Minisci

The elderly who stay outside hospitals and nursing homes are frequent recipients of home care services. These are recurring visits made by a trained professional who performs some prescribed tasks for the beneficiary. Due to a large number of residents eligible for the service and the cost of its provisioning, optimization of home care operations has an important societal impact.

The schedule and routing optimization for home care workers can be formulated as a variant of the Vehicle Routing Problem with Time Windows, for which efficient solution methods are readily available. The success of such an approach heavily depends on the availability of estimates for visit durations. We forecast these by splitting historical records collected for each customer into clusters. Visit durations in the same cluster are then projected on the date dimension and considered as a time series. Most importantly, some of the time series observed in the real world are non-stationary, which is a strong indicator in favor of our approach. After the trend and the seasonality component are detected, the estimate of a future visit duration is computed using out-of-sample forecast.

For the examples considered, the proposed forecasting method is superior to the predictions made by human planners. Furthermore, when used in the schedule optimization, we observe a significant reduction in the need to hire agency staff and the overtime registered for a schedule executed in the real world.

2 - Modeling Mobile Health Service Delivery to Syrian Migrant Farm Workers using Call Record Data
Sibel Salman, İlker Kayi, Sedef Turper, Eda Yücel

A significant number of Syrian refugees under temporary protection in Turkey work in agriculture seasonally in various rural areas during a year. These migrant farm workers and their families are deprived of access to the regular healthcare system and preventive services due to their remote locations. The government supports the delivery of different types of mobile healthcare services, such as vaccination for children, reproductive health and screening services. However, it is critical to know where the refugees work during what time frame. By analyzing call record data of a major mobile network operator in Turkey, we quantify the increase in the volume of calls made by Syrian refugees in various agricultural areas during the harvesting season of local crops. This information helps us to identify spatial and temporal distribution of demand for mobile healthcare services at a fine granularity. Taking demand over multiple periods as input into a mathematical programming model, we optimize the routing of the mobile facilities which visit the locations where refugees are concentrated over the given planning horizon. The objectives are to cover a maximum number of refugees within specified distances and to minimize the total distance traveled by the facilities, given a specified number of mobile facilities. By sensitivity analysis, we show that the decision makers can identify the number of facilities and personnel needed to cover a desired level of potential patients.

3 - A reactive algorithm for a dial-a-ride problem with real-time disruptions
Célia Paquay, Yves Crama, Thierry Pironet

The problem considered in this work stems from a non-profit organization in charge of transporting patients from their home to medical appointment locations and the other way around. The aim of this work is to propose a reactive algorithm for this dial-a-ride problem to adapt the planning in order to manage real-time disruptions, such as patient delays or appointment cancellations. Our work aims at adapting the current solutions so as to manage the disruptions while accounting for three potentially conflicting objectives, namely: satisfying all patient requests, to the best possible extent; limiting the planning changes, so as to avoid confusion for the drivers and patients; and minimizing the patient excess journey duration, as a measure of service quality. Moreover, the dispatcher should be able to react quickly, so as to take care of the patients as early as possible and to define the recourse action before the next disruption occurs. The proposed reactive algorithm explores small neighborhoods of the current solution and very progressively enlarging these neighborhoods in order to restore feasibility when a perturbation occurs. As a secondary objective reflecting the quality of the modified plan, when feasibility is restored, we try to minimize the excess journey time ratio of the patients. Disruption scenarios have been generated and discrete event simulation has been used to observe the behavior of the algorithm on several types of instances.

■ WA-36

Wednesday, 8:30-10:00 - Q010

Heuristics for Vehicle Routing Problems I

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Majid Eskandarpour*
Chair: *Raquel Bernardino*

1 - A Genetic Algorithm for the Hazardous Materials Vehicle Routing Problem in Urban Areas
Nikolai Holeczek, Tobias Baumgaertner

The transportation of hazardous materials (hazmat) has attracted much attention in the last decades. The dangerous nature of the cargo and the resulting threat for population, environment and infrastructure requires the inclusion of risk in the decision problem. For the purpose of safety, hazmat vehicles should avoid to drive through regions with a high population density. However, hazardous materials like heating oil, fuel gas or gasoline often need to be distributed in highly populated urban areas and to multiple customers. In this paper, the capacitated hazardous materials vehicle routing problem (CHMVRP) with multiple customers in urban areas is addressed. The varying amount of hazardous cargo during a vehicle trip is incorporated in the considered risk model. A genetic algorithm metaheuristic framework is adapted to the CHMVRP and applied on a random generated but realistic road network of an urban area. The multi-criteria conflict between travel distance and risk minimization is addressed and a pareto front is constructed.

2 - A Large Neighborhood Search for the Active-Passive Vehicle Routing Problem
Biljana Roljic, Fabien Tricoire, Karl Doerner

The active-passive vehicle routing problem (APVRP) is a variant of the vehicle routing problem in which pickup-and-delivery requests require a joint operation of two types of transport resources, namely, passive and active means of transport. The passive means are used for holding the cargo, representing a single unit that is to be shipped from pickup to delivery locations. The active means haul the passive means and carry them from one location to another. The contribution of our work is twofold. First, we investigate the classical APVRP and provide a fast metaheuristic able to address large benchmark instances. We design our method such that we realize more opportunities for optimization by allowing the transshipment of passive means among active means during the fulfillment of single pickup-and-delivery requests. Second, we introduce an extended version of the APVRP, where passive means can hold multiple units up to a maximum capacity. This extension is motivated by a real-world problem setting in integrated steel production, concerning intra-facility steel slab routing. We report computational results for the classical APVRP and show that our metaheuristic provides competitive performance on benchmark data sets. As for the extended APVRP, we create new instance sets conforming to the specific problem characteristics. Our contributions are completed by a thorough analysis of the possibilities and limitations of transshipments as part of the classical and extended APVRP.

■ WA-37

Wednesday, 8:30-10:00 - Q011

Mathematical Models in Macro- and Microeconomics 1

Stream: Mathematical Models in Macro- and Microeconomics
Invited session
Chair: *Alexander Vasin*
Chair: *Gerhard-Wilhelm Weber*

1 - A Probabilistic Economic Model to Estimate the Number, Lifespan or Creation Rate of New Businesses
Marcelo Alencar

Economic parameters, such as the number of companies in a given year, rate of opening of new businesses or number of bankruptcies, are characterized as non-stationary stochastic processes. This modeling is usual for developing countries, in which the population did not reach stability. Developed countries are typically in statistical equilibrium. There is a strong correlation between the rate of opening of new businesses and economic growth. The growth increases the demand for products, which induces the opening of new companies to produce them. The creation of businesses induces the growth of the economy, because it generates more jobs and revenue. This article presents a model to computation economic parameters, such as the number of active companies. The model can be used to predict the number of companies, or the bankrupt rate in the future or to estimate some economic indices.

2 - Let's Play the Game for the Future of Digital Services in Serbian Schools
Mara Bukvic

This work is focused on the analysis of circumstances/settings that stalled the process of providing internet connectivity for primary and secondary schools in Serbia through the National Research and Education Network (NREN) for nearly a decade. Despite the fact that both a lack of vision/plans and insufficient funding are often identified as the first order barriers in a diffusion of technology in developing counties, our research was based on assumption that neither of them impedes the process in this case. Further on, one can find the activities that have been successfully applied to return this long-term goal among top priorities of government and funding bodies. These activities were chosen after modelling the situation based on the principles in the field of game theory. The starting point of the work was to apply the framework of the agency theory to the non-profit environment of NREN in which the government founded the NREN to provide IT services to third parties i.e. research and education institutions. We decided to share the model description along with the experience gained in Serbia, with the aim to avoid/affect similar situations in future and to encourage anyone who recognizes an analogy with their current position, may it be a person or a community, to act in their own creative way instead of waiting for someone else to do the same, whenever he/she believes that could contribute to the community to override/cut across difficulties.

3 - Resource Allocation in New Product Development: Internal vs. External Projects
Hossein Nikpayam

New product development (NPD) is the process of turning novel ideas into technologically feasible and economically successful products in the market. Senior management manages this process through resource allocation to different NPD projects. The decision of whether or not to pursue an NPD project has vital importance for almost any firm's success. The NPD projects under consideration for the resource allocation can include projects developed internally in the firm, as well as external projects developed outside of the firm. Bringing the external projects into the resource allocation decision adds to the complexity of the problem. Competition between internal R&D teams and external actors changes the underlying economics. Although there is a vast literature on resource allocations to internal projects, academic papers that study NPD portfolio management in collaboration with external partners are scant. Thus, the aim of our project is to investigate how firms should allocate resources to NPD initiatives, when they have access to a pool of internal and external projects. We particularly want to study the agency issues corresponding to this setting, and find out ways to manage their impact.

4 - Convexity in games with externalities
Mikel Alvarez-Mozos, José María Alonso-Meijide, Maria Gloria Fiestras-Janeiro, Andrés Jiménez-Losada

We propose a new definition of Convexity for games with externalities and compare it to the one defined by Hafalir (2007). Our approach is based on a partial order among embedded coalitions that was first considered by Bolger (1990) to define monotonicity for certain games with externalities. We formalize it and study the structural properties of the set of embedded coalitions endowed with this partial order. We see that it is not a lattice, but a graded poset. We characterize the infimum and supremum whenever they exist and count the number of elements at a given height as well as the number of chains. All these results allow us to derive the coefficients of any game in the basis of unanimity games in partition function form. Our main game theoretic contribution is the equivalence of our notion of convexity with players having non-decreasing marginal contributions to embedded coalitions of increasing size.

■ WA-38

Wednesday, 8:30-10:00 - Q012

Decision Aiding Methods 4

Stream: Multiple Criteria Decision Aid
Invited session
Chair: Menelaos Tasiou

1 - A balanced development? The novel σ-μ efficiency applied to the ranking of Italian regions
Gianpiero Torrisi, Salvatore Greco, Menelaos Tasiou

The use of composite indicators experienced significant momentum in recent years within academia, policy makers, and global institutions. Despite the burst of popularity, an ongoing criticism has been developed around their computation with respect to both weighting and aggregation. In brief, weighting involves the relative importance of the attributes chosen, whereas the latter involves the process that transforms them into a single value. This study builds upon a very recent methodological contribution - the σ-μ efficiency (Greco et al., 2018) - that takes into account both issues by combining the use of Stochastic Multiattribute Acceptability Analysis with a maximisation approach which accounts for both the average performance and its spread. When applied to the Italian regional case-study the σ-μ efficiency while confirming the overall North-South divide, shows a more nuanced picture with interesting differences with respect to well-established alternative aggregation techniques such as equal weight and Mazziotta-Pareto index.

2 - Multiple criteria hierarchy process for robust measurement of countries' innovation performance in Europe
Ana Garcia-Bernabeu, Salvatore Corrente, Salvatore Greco, Teemu Makkonen

In today's complex globalized economy, innovation lies at the core of any solution facing global economic challenges and is considered as the main driver for sustained economic progress and competitiveness. Therefore, the measurement of innovation has received significant attention from policy-makers and researchers in order to develop integrated benchmarking systems to compare and evaluate the efficiency/performance at different levels: national, regional or global. Although, there exists a wide variety of composite innovation indices (CIIs), there is no consensus on the most suitable methodological framework and it is acknowledged that modelling assumptions can have a significant impact on the CIIs scores and ranking, with the weighting and aggregation system being of particular concern. In this research, we propose an appraisal Multiple Criteria Decision Aid (MCDA) methodology based on the information provided by the European Innovation Scoreboard. This approach combines the Multiple Criteria Hierarchy Process (MCHP) with the Stochastic Multicriteria Acceptability Analysis (SMAA) and the Choquet integral preference model. This framework permits to take into consideration the interaction of pillars that constitutes the index as well as robustness concerns related to the elicitation of weights assigned to the pillars.

3 - Defining poverty and identifying strategic objectives for the United Nations developing countries with the use of Dominance-based Rough Set Approach
Bryan Trudel, Jean-Charles Marin, Kazimierz Zaras

The aim of this research is to expose the results of using Dominance-based Rough Set Approach to help International organizations define poverty, identifying economical, sociological, political and technological strategic objectives for developing countries. More precisely, politicians, decision makers and international organizations will be able to study 23 various indicators on all the 193 member states of the United Nations. These variables were then classified into four perspectives, political, economical, sociological and technological. Every country has been classify to the following three categories: [A] Countries that are doing well to the selected indicators; [B] Countries that need support to acquire category A status; [C] Countries ranked the lowest. The three categories are delimited by tertiles relative to the average ranking of the member states of the United Nations. The chosen criteria are measured in order to pro-vide decision rules based on this classification. These decision rules thus focus on the strategic needs of countries with respect to improving their development and classification. By targeting these identified needs, this research will help the development of countries in need to set realistic targets, prioritize International funding, evaluate economical growth and sociological improvements. Among the results of this research, priorities for countries ranked C should focus on reducing adolescent fertility and increasing school life expectancy.

4 - Sigma-Mu-SMAA-PROMETHEE

Menelaos Tasiou, Salvatore Greco, Alessio Ishizaka, Gianpiero Torrisi

We propose a methodology employing PROMETHEE methods to produce non-compensatory composite indicators taking into account robustness concerns related to weights assigned to the elementary indicators. PROMETHEE methods have been very successful over the years, providing much appreciated recommendations based on inflows and outflows measuring, for each alternative, its weakness, its strength and their balance. In this context, one can take into account robustness concerns related to the stability of results with respect to the values assigned to weights and indifference and preference thresholds, with a SMAA variant of the PROMETHEE methods recently proposed. Taking advantage of these good properties, we provide a new approach based on PROMETHEE methods to aggregate in a composite indicator the evaluation supplied by heterogeneous elementary indicators. The methodology we propose is based on a mix of well-known operational research methodologies that encapsulates the SMAA-PROMETHEE probabilistic outcomes in a single, holistic evaluation. Moreover, we introduce another variant of the SMAA-GAIA visual aid, providing the decision-maker with some analytical insights of the performance of a unit of interest. We illustrate the advantages of this approach, presenting a case study of socio-economic inclusive development, using the data of the homonymous report produced by the World Economic Forum.

■ WA-39

Wednesday, 8:30-10:00 - Q014

Real-world timetabling applications

Stream: Timetabling
Invited session
Chair: Valentina Cacchiani

1 - EURO-2019 conference scheduling: Use of session patterns

Thomas Stidsen

Scheduling the sessions of the EURO-2019 conference is a complex problem, where more than 400 sessions have to be placed in rooms and timeslots. In this talk we will describe how EURO-2019 was planned, utilizing an approach, based the sequential solution of Mixed Integer Programming (MIP) models. The focus in this talk will be on the use of session patterns, i.e. for each stream there are variables, corresponding to a specific timeslot allocation. This approach reduces the number of (binary) variables in the MIP models significantly, compared to the direct formulation, decreasing the solution time from hours to minutes. Generating these timeslot patterns, are however not trivial, due to a large number of special requirements for the streams.

The work on the models behind the EURO-2019 conference, is based on the previous scheduling of the conferences, EURO-2015, EURO-2016, IFORS-2017 and EURO-2018. The details for the approach for EURO-2016 is documented in our previous article "Scheduling EURO-k conferences", Stidsen et al, EJOR, 2017.

2 - Suggesting Timetable Perturbations in Dynamic Educational Timetabling

Rasmus Ørnstrup Mikkelsen, Matias Sørensen, Thomas Stidsen

Educational timetabling is a classic and important problem within Operations Research. Most research attention has been given to the static problem of timetabling whole semesters at a time, while research within more dynamic methods is scarce. As a consequence, many timetabling systems lack proper support for helping planning staff change established timetables in a helpful way. In this paper we present an approach for supporting planners in making focused changes to a timetable, by providing a number of suggested timetable perturbations based on user input for whom the timetable should be improved. The method is implemented in a decision support tool that can help planners both make the initial semester timetable and to handle timetable disruptions that inevitably occur. This is a Mixed Integer Programming (MIP) approach based on extending the model for the High School Timetabling problem in Denmark. We show how such a MIP can be adapted to force timetable perturbations and to prefer positive changes for user defined persons. By iteratively adding cuts to the problem different suggestions are found. Since the models can be quite extensive, an approximation model is proposed. A series of computational tests are performed on real world data using two different MIP solvers. These results are analyzed in conjunction with experiences from planners using the tool in practices, to provide better insights into the applicability and performance of the method.

3 - Examination timetabling in practice: A real-world application to Italian universities

Andrea Schaerf, Michele Battistutta, Sara Ceschia, Fabio De Cesco, Luca Di Gaspero, Elena Topan

We investigate the examination timetabling problem in the context of Italian universities. The outcome is the definition of a general problem that can be applied to a large set of universities. This formulation is different in many aspects from the classical versions proposed in the literature (e.g., the one in the Timetabling Competition ITC-2007), as it involves many peculiar real-world constraints and objectives. For example, some exams are composed by separate written and oral part, which must be scheduled at suitable distance and have different conflict acceptability levels in relations to other exams. In addition, the same exam might be repeated more than once in a session, with prescribed minimal distances among rounds. As another quite distinctive feature, exams might require multiple rooms, typically in exclusive use. In this work, we propose a solution approach based on simulated annealing and a statistically-principled parameter tuning, building upon our experience on other timetabling problems. In addition, we are collecting many real-world instances to be made available to the community for comparison, that could potentially become a future benchmark. This is an ongoing work, so that results and data will be reported at the conference.

4 - Modeling and solving a real-world nurse rostering problem

Sara Ceschia, Vincenzo Mazzaracchio, Giuseppe Policante, Andrea Schaerf

The Nurse Rostering Problem consists in assigning a shift or a day-off to each nurse for all days of the planning horizon. The schedule has to take into account several constraints related to optimal coverage, nurse contracts, and personnel preferences. In this work, we study a real-world problem formulation defined in collaboration with Windex s.r.l., coming from experience with many Italian health facilities. In detail, we consider a free planning horizon (not fixed to a multiple of a week), heterogeneous shift types depending on the nurse qualification and on the hospital department, ad hoc contracts for nurses, and different types of day-off (rest, holiday, absence). Many constraints related to the job contract are evaluated not on the number of assignments but on the number of hours, given that the duration of shifts can be significantly different. In addition, we introduce constraints that guarantee a fair distribution of shifts and balance the simultaneous presence of men and women, and of expert and junior personnel. Finally, we include the possibility to express both incompatibility between nurses and favorite work-teams. We propose a local search technique, which uses a composite neighborhood based on replacements and swaps of nurses, for multiple consecutive days. This is an ongoing work, and the method will be tested on a set of instances that we are collecting from many hospitals, that we plan to make available on the web, once conveniently made anonymous.

■ WA-40

Wednesday, 8:30-10:00 - Q015

Real-Life Vehicle Routing Problems

Stream: Vehicle Routing and Logistics Optimization II
Invited session
Chair: Iris Forma

1 - Dynamically routing ambulances to patients with multiple types of vehicles and multiple response

Laura Albert

Emergency medical service (EMS) systems have two main goals when sending ambulances to patients: rapidly responding to patients and sending the right type of personnel to patients based on their health needs. We address these issues by formulating and studying Markov decision process models that determines which type(s) of ambulances (servers) to send to patients in real-time. The base model considers a loss system over a finite time horizon, and it dynamically assigns servers to patients. We present a model extension that allows for multiple response, which enables faster response times and better matches vehicle types to the patients' uncertain needs at the potential cost of making more vehicles unavailable at any given time. Structural properties of the base model's optimal policies are derived to characterize the optimal resource assignment strategy. We show the conditions under which there exists an optimal policy that is a signal threshold type and a state control limit type. Computational experiments using real-world emergency response datasets show that the dynamic policies significantly improve system performance by informing how to dynamically update ambulance-patient matching. Moreover, the experiments demonstrate that multiple response can significantly improve system performance as compared to basic care by more frequently providing advanced care to patients whose health needs are uncertain.

2 - Optimization-based Heuristics vs. Meta-Heuristics to Solve the Smart Waste Collection Routing Problem

Carolina Soares de Morais, Raquel Pena Aguiar, Tania Ramos, Ana Barbosa-Póvoa, Diana Rita Ramos Jorge, Antonio Antunes

The Smart Waste Collection Routing Problem was proposed by Ramos et. al. (2018) and is characterized by exploring the access to real-time information on the bins' fill-level, transmitted through sensors installed in the waste bins, so as to reduce uncertainty and to improve waste collection operations' efficiency. The problem was modeled as a Vehicle Routing Problem with Profits maximizing the collected waste while minimizing transportation costs. However, due to the complexity of the proposed model, low computational performance and low solution quality (significant gaps) were obtained when solving real-world cases. In this context, two heuristic approaches are proposed in this work to improve the solution performance of such model. The first one is an optimization-based heuristic, where some criteria, namely spatial and fill-level rates, are tested to decompose the problem where the VRPP mathematical model is solved for smaller problems. The second approach is a hybrid simulated-annealing/local-search metaheuristic with parameters obtained through an automated calibration algorithm. To test the proposed new approaches, data from a real case is used, where the routes for 226 waste bins are to be planned over a 30-day planning horizon. The results obtained with the two approaches are compared between them and with the monolithic VRPP model.

3 - A multi-period attacker-operator model considering recovery time

Hande Kucukaydin, Necati Aras, Aylin Oncu

Intentional man-made attacks on transportation networks can result in serious disruption on passenger flow. Such an attack can arise, for example, in case of a terrorist activity. If these attacks are carried out by an intelligent agent, the magnitude of the loss and disruption goes up dramatically. Therefore, it is crucial to find out how fragile the components of a transportation network are as it belongs to the critical infrastructure supply chain networks. The aim of this study is to formulate a multi-period attacker-operator model in order to identify the most vulnerable stations of a transportation network. The mathematical model developed is a bilevel programming model, where the leader is a virtual attacker who wishes to cause the most damage on the stations in order to minimize the passenger flow in the network and the follower is the system operator who wishes to reorganize the flow in the most effective way so that the passenger flow after the attacks is maximized. Furthermore, it is assumed that the interdicted stations become fully functional after a certain repair time referred to as the recovery time.

4 - Functional decompositions of integrated supply chains

Iris Forma, Tal Raviv, Michal Tzur

We introduce production, inventory, distribution, and pickup routing problem (PIDPRP) and formulate it as a MILP. Our model includes the key supply chain operational decisions of a manufacturer. It generalizes several NP-Hard routing and scheduling problems. Ideally, any centrally managed chunk of the chain should be solved as an integrated problem, where all decisions are made simultaneously. However, since it poses a highly intractable problem, we explore several possible decomposition schemes to reduce the problem to more manageable sub-problems. We present three new functional decomposition approaches. After the problem is decomposed according to the selected heuristic, the sub-problems are solved using mathematical programming formulations and a route generation heuristic. We then report on an extensive numerical study that we conducted based on 210 randomly generated problem instances. Based on our results, we propose guidelines for choosing the most effective decomposition.

■ WA-41

Wednesday, 8:30-10:00 - Q013

Infrastructure and Line Planning

Stream: Public Transportation I
Invited session
Chair: *Andrea D'Ariano*
Chair: Juan A. Mesa

1 - A Benders Decomposition Algorithm for Solving the Line Planning Problem for High-speed Rail

Bisheng He, Andrea D'Ariano, Yihui Wang

Line planning aims to determine a set of operation lines with routes and frequencies to meet passenger demand. The optimal line planning can serve the transport demand with efficient utilization of resources at a high level of service quality. In the high-speed railway, transfer connection between services is the very essential point for the convenience and satisfaction for passenger mobility. A time-space network is adapted to acquire the service line frequency for each operation hour to schedule the passenger transfer connection. A line planning problem is molded including frequency setting and passenger assignment to minimize the total passenger travel time and dissatisfaction of transferring. The Benders decomposition method is proposed to solve the model. The idea of Benders decomposition algorithm is that, if a feasible service line frequency is acquired by the first stage frequency setting problem, the remaining model is the second stage passenger assignment problem which is defined as a sub-problem. The result of passenger assignment problem, which is a multi-commodity network flow problem solved by the column generation method, can be added as a new cut for the frequency setting problem. Several speed-up strategies have been implemented to improve the process of Benders decomposition. Experimental results based on real-world problem instances show that our approaches could be a promising way for solving line planning problem of high-speed rail.

2 - The reconstruction of the railway transport system in the service of Port of Rijeka development
Siniša Vilke, Neven Grubisic, Tomislav Krljan

In this article the authors emphasize the significance of the reconstruction of the railway transport system for the development of the Port of Rijeka. The most important projects related to Rijeka's rail transport system are the construction of a new high-efficiency railway Rijeka - Zagreb and a new high-efficiency railroad which will link Rijeka, Koper and Trieste ports. The construction of a new high-efficiency railway Rijeka - Zagreb and a new high-efficiency railway Rijeka - Koper - Trieste will create a significant shortening of railway connections of South East Europe with its central and western parts, and will improve the conditions of traffic exploitation, i.e. future development of the port of Rijeka. The aim of this paper is to show that the application of the multi-criteria analysis can lead to conclusions regarding the selection of the adequate railway transport route. For selecting the railway route connecting Rijeka, Koper and Trieste the PROMETHEE II method for multi-criteria ranking of alternatives is used.

3 - Design of lines for minibus services
Marie Schmidt, Evelien van der Hurk

In cities with underdeveloped public transportation systems, minibus service can be a valuable addition to metro, tram, and/or bus transportation. Compared to these alternatives, minibuses are more flexible. Service can be a relatively cheap way to increase coverage and can be tailored to demand, for example via street hailing or requests made using mobile applications. Fast algorithms and opportunities for close to real time application between operator and customer, allow minibus service to operate in a much more flexible manner than traditional public transport systems. In this talk we address the strategic decision of designing a strategic line plan for these minivans, where a line is a directional corridor within a city containing a candidate set of stops, which can be either visited or skipped based on real time demand. Our goal is to maximize the coverage of the minibuses, particularly in areas not covered by competing transportation systems.

4 - Solving Transportation Infrastructure Network Design Problems by Benders Decomposition
Juan A. Mesa, Natividad González-Blanco, Martine Labbé, Bernard Fortz

Network design problems appear everywhere and are usually difficult combinatorial ones. For this reason heuristics and metaheuristics are often applied in order to get good solutions in a reasonable time. In transportation planning, network design is the first step of the sequential planning process. Given an underlying network the problem consists in selecting a set of edges and nodes forming a subgraph so that some objective function is optimized. Network design is a crucial part of the transportation planning since often the construction of the resulting network is very expensive, and then cannot be changed, and because all other activities have to be carried out along the network designed. Usually when a transportation infrastructure is planned there is other transportation mode already functioning for which reason it should be taken into account in order to improve the mobility of the population. Several objectives can be fixed when planning a transportation infrastructure network among them the population and trips covered, and the cost of the new network are among the most important. In this work, we consider two intertwined problems: to maximize the number of trips captured by the planned network subject to budget constraint and to minimize the total cost of constructing the network subject to a proportion of the travelers will use the new public network. Several variants of Benders decomposition are applied to solve these problems.

■ WA-42

Wednesday, 8:30-10:00 - Q113

City logistics II

Stream: Transportation
Invited session
Chair: Hiroyuki Goto

1 - Decision support system for last mile delivery issues
Vijay Paidi, Roger G Nyberg, Johan Håkansson, Hasan Fleyeh

E-commerce has evolved over the years leading to increased demand, business and sophisticated logistics network. In business to consumer operations, consumer satisfaction and acceptance are necessary for the success of business and increase in demand and value. Logistic companies must manage the deliveries or pick-ups efficiently with available resources to reduce transportation costs and make the service sustainable. This paper discusses last mile transportation problems such as customer unavailability, inefficient schedule of delivery routes and the usage of loading and un-loading bays by the delivery trucks. The literature discusses issues such as vehicle routing problem, additional costs for missing deliveries and various models of distribution. Therefore, a decision support system is proposed along with use cases which holistically address these issues making it suitable for delivery companies. The decision support system comprises of driver and customer applications to address the issues. One mid-sized delivery company performed pilot test of the decision support system in Dalarna county of Sweden. The optimized routes provided by the decision support system lead improvement up to 12.6% with no missing deliveries. However the improvement is subjected to the experience of driver and location of deliveries or pick-up. The system can be improved further based on feedback received from the delivery company and customers.

2 - City Logistics Systems, Consolidation, and Coordination
Haldun Sural, Mohammad Saleh Farham, Cem Iyigün

City Logistics (CL) aims improving urban freight transportation systems, integrating the individual actors, and managing segmented components of freight transportation by considering the costs and benefits to the society. In this presentation, we study CL systems from strategic, tactical, and operational decision-making perspective. We concentrate on network design models for CL systems which incorporate its consolidation component. We answer the question of how well related OR/IE problems can help formulating these models by identifying the dis/advantages of the problems in real-life. We also investigate two aspects of coordination in CL systems and illustrate different aspects of CL by numerical examples.

3 - Car Traffic Management System with Cellular Automata
Eduard Franti, Monica Dascalu

This paper presents an interactive and centralized real time system for monitoring, diagnosis and prediction of traffic evolution in Bucharest. The system consists of a traffic simulator (updated with real traffic data), a module for the acquisition and transmission of the traffic data and a module for the analysis and prediction of the car traffic evolution, both globally and on each street. The cellular automata (CA) model was used for the car traffic modelling as realistically as can be. The CA are a massive parallel computing system, and despite the fact that they have a simple functional structure, they can be successfully used for the simulation of some complex systems (like car traffic). The simulator was implemented for the real traffic map of Bucharest, including all streets, crossroads, crosswalks, traffic lights and road signs. To implement the simulator, a library of algorithms and local evolution rules has been designed for several functions, including traffic modelling for multiple lanes, crossroads with traffic lights, irregular crossroads with no traffic lights, pedestrian crossings, parking spaces etc. The system presented in this paper has a high level of autonomy and will generate many positive and sustainable economic effects like reducing the level of pollution, increasing the intervention efficiency of the ambulances, firefighters and police cars, better management of street repairs, etc.

4 - Reduction in time complexity for computing overlaid traffic flows
Hiroyuki Goto, Yohei Kakimoto, Panote Prommas, Yoichi Shimakawa

An approach to approximate estimation of traffic flows on a road network is to accumulate passage counts for all origin-destination (OD) pairs. The significance of this approach is completeness; relative extent of traffic loads on all links can be estimated. The computation load, however, has been high as we have to seek an optimal route for each OD pair. In this context, we aim to reduce the computation time for overlaid traffic flows based on shortest OD policy. The major approach heretofore has been combination of finding a shortest path followed by increments of traffic counts along the optimal route. While the bottleneck seems on the former, the actual has been on the latter: tracking backward along the optimal route. We thus concentrate on improving the latter to reduce the total computation time. Alongside a priority queue-based algorithm such as Dijkstra's algorithm, given a single source node, the shortest paths are sought and determined toward distant nodes. The sorted shortest distances would be preserved, thereby we effectively reuse this in the second procedure. Starting from the most distant node from a source node, we step backward to its predecessor node to accumulate traffic flow. This is conducted only for a single step, then we would jump to another distant node from the current one. Repeating this procedure, we obtain the same outcome as that based on conventional algorithms. While simple in implementation, the reduction effect is significant.

■ WA-43

Wednesday, 8:30-10:00 - Q114

Hub Location II

Stream: Location Analysis and Optimization
Invited session
Chair: *Enrique Dominguez*
Chair: *Jenn-Rong Lin*

1 - Competitive Intermodal Hub Location Problem with Endogenous Pricing
Mohammad Reza Mousavi Almaleki, Salih Tekin, Gultekin Kuyzu

Road transportation has successively captured the transportation market which is resulting in an unsustainable economy with congestion and environmental problems. In order to achieve a more sustainable environment, inter-modality can be planned in logistics networks. To be able to utilize the economy of scale and reduce the transportation cost in the logistics network, rail competitor is being considered in a hub-spoke model. When a new transportation mode is entering to the market, it is important to notice that demand of customer would not stay unchanged. The level of service that the entrant firm is providing can determine the customer behavior. Of the most important factors in customer behavior is the price that the firm is charging. We evaluate price sensitive demand in our model.To do so, a discrete choice logit model will be applied.To the best of authors' knowledge, there is no work modelling the competitive intermodal hub location problem with endogenous demand that is being captured by discrete logit model as a function of price. This frame work is more reasonable in modeling the flow transitions after entering the new firm to the market. Moreover, actual data for rail transport is being considered in the model. Optimal price strategy is derived out of the MINLP model. Logit model enables us to evaluate sensitivity analyzes on market share and price strategy all over the profit maximization of the rail transportation.

2 - Deterministic and robust models for a multimodal capacitated Hub Location Problem with multi-commodity: A case study in Chilean export process
Alan Osorio, Rodrigo Linfati

Hub Location Problem (HLP) concerns on strategic decisions of location of logistic nodes and flow allocation. This study presents a new mixed integer lineal programming model for a multimodal capacitated HLP with multi-commodity, and its robust version. The novel features of the model are direct shipment and origin/destination flow allocation as part of the decision (not as parameters). The models are implemented in C+ and solved using commercial solver CPLEX. Instances correspond to Chilean export process, considering actual and projected flow. Upon 100 nodes, six products and two transport modes (train and trucks) are part of the case study. The results indicate that if we only consider cost, just one hub is profitable for the system. The best location for a hub is in the south of the study area, reporting annual transport savings close to 1%. Flow concentration and distances between hubs and destinations (costs and travel times) are the key factors in location decision. The proposed models are valid tools to support strategic decision making in multimodal freight transport.

3 - Integrated hub location and flight scheduling
Aykan Akincilar, Sibel A. Alumur

In this study, a new integrated problem for airline operations planning, covering both strategic and operational levels, is introduced. In particular, flight scheduling decisions are integrated into the hub location problem to investigate the impact of such decisions on the design of hub networks. A mathematical model is developed and tested on real data that is collected from a major firm in Turkey to analyze the effect of integrating flight scheduling on hub network design.

4 - The robust planning of last-mile delivery systems
Jenn-Rong Lin, Wei-Ming Wu

The purpose of this study is to formulate and analyze a robust planning model for last-mile delivery systems with smart locker storage space capacity considerations. The key planning decisions considered are: the number and locations of smart locker stations in the system, the number of smart lockers to be held at the smart locker stations and the routing of shipments through a smart locker station between parcels distribution centers and customer locations. The planning decisions are made with concern for both total cost and service levels (measured both by fill rate for shipments storage at the smart locker station and coverage of the customers). The planning problem is formulated as a hub location inventory model. Numerical examples are created to illustrate and to test the proposed model.

■ WA-45

Wednesday, 8:30-10:00 - Q117

Decision Making in Sustainable Transportation

Stream: Green Logistics
Invited session
Chair: *Javier Faulin*

1 - A novel approach to the tail assignment problem in airline planning
Luis Cadarso, Manuel Fuentes, Vikrant Vaze, Cynthia Barnhart

Airline planning is a field rich in combinatorial optimization problems. Flights and airports make up the network where aircraft and passengers fly. In order to schedule aircraft, assignments of fleet types to flights and of aircraft to routes must be determined. The former is known as the fleet assignment problem while the later is known as the aircraft routing problem in the literature. Aircraft routing is usually addressed as a feasibility problem whose solution is needed for constructing crew schedules. All these problems are usually solved from 4 to 6 months before the day of operations. Therefore, there is limited information regarding each aircraft's operational condition. The tail routing problem, which has received limited attention in air transportation literature, is solved when additional information regarding operational conditions is revealed aiming at determining each aircraft's route for the day of operations accounting for the originally planned aircraft routes and crew schedules. Therefore, it is a problem to be solved the day before operations. We propose a mathematical programming approach based on sequencing that captures all operational constraints and maintenance requisites while operational costs are minimized and schedule changes with respect to original plans are minimized. Computational experiments are based on realistic cases drawn from a Spanish airline, which features a network with more than 1000 flights and more than 100 aircraft.

2 - Some Protocols to Internalize Negative Externalities in Delivery Policies for Companies
Javier Faulin, Adrian Serrano, Luis Cadarso

Usually, freight transportation considers various internal and external costs that need to be accounted for in the delivery policies for companies. While the traditional focus of the Vehicle Routing models was the minimization of internal routing costs such as travel distance or duration, numerous approaches to include external factors related to environmental routing aspects have been recently discussed in the literature. Nevertheless, internal and external routing costs are often treated as competing objectives. Doing a different approximation, this work considers the internalization of external costs within the economic structure of the logistic company. Thus, not only the traditional approach of distance based internal costs of routing is considered but also the external costs are included in the objective function: that is, we are going to consider the minimization of the full costs. Two protocols of internalizing are further analyzed and discussed: green taxes and green tolls. Numerical experiments with a biased-randomization savings algorithm show benefits of combining internal and external costs in delivery route planning. Consequently, the behavior of companies when internalizing external costs significantly changes. That means that they plan a different route in order to minimize their full costs, allowing for a noticeable reduction on emissions.

3 - Development of a Shared-Based Virtual Logistics System
Gyusung Cho, Jaemin Kim

In the logistics sectors by the 4th Industrial Revolution, it is necessary to find the best optimization by the establishment and operation of shared-based logistics systems. In response to this demand, we suggest a case study to modify and analyze a shared-based virtual logistics system which is built on actual port container terminal operation data. We show how to establish the suggested system and calculate the performance. The research methodology presented in this study will be considered to be a basic study that can increase the efficiency through design and analysis of shared-based logistics systems.

■ WA-46

Wednesday, 8:30-10:00 - L243

Fuzzy Optimization I

Stream: Fuzzy Optimization
Invited session
Chair: Daniel Gomez Gonzalez

1 - Applying a Fuzzy Aggregator to Segment User Profiles Based on Their Opinions
Jennifer Nguyen, Albert Armisen, Nuria Agell, German Sanchez, Xari Rovira

In a recommender platform context, we propose a user profiling method based on the ratings and attributes of individuals using the system in their search for an item. This user profiling method allows recommender systems to assist users with finding items suited to their personal preferences. Preferences are derived from topic analysis on the user's previous reviews which he introduced on the platform after experiencing an event and integrated with user provided attributes. We propose a new fuzzy machine learning approach based on a measure of similarity between users considering categorical variables. The similarity measure uses a fuzzy aggregation operator. This proposed method differs from previous similarity measures in three ways. First, the method considers the frequency distribution of each possible value of an attribute within each cluster rather than the frequency of a value in the entire dataset. Second, the method does not view a match simply by a match or mismatch rather it compares the similarity of the frequency distribution of attribute values between two clusters. Third, the method applies a parameter of tolerance which may or may not favor the frequently matched attribute values in a cluster. The model is implemented in a real case dataset of restaurants from the Yelp platform.

2 - Aggregation of Experts' Evaluations Based on a Fuzzy Equivalence Relation
Svetlana Asmuss, Pavels Orlovs

The talk is devoted to a special design of aggregation operators introduced via fuzzy equivalence relations. The need of such operators appears in decision making based on aggregation of evaluations provided by several experts and represented by fuzzy sets. In the case when the similarity of objects under evaluation is described by means of a fuzzy equivalence relation, it is important to include this relation in the aggregation process. The motivation is as follows: in order to obtain the evaluation of some object it is important to take into account how the experts evaluated similar objects. We describe how the proposed construction could be applied for risk level assessment in the case when a strong fuzzy metric is used to characterize the similarity. The technique is illustrated with examples of aggregation of experts' evaluations of the investment risk level for some countries using an equivalence relation obtained on the basis of different macroeconomic factors. This research has been supported by the project LZP-2018/1-0338.

3 - A Fuzzy Aggregation Approach for a New Color Edge Detection Algorithm
Daniel Gomez Gonzalez, Javier Castro, Guillermo Villarino, Pablo A. Flores

Dealing with color images for edge detection problem is an open problem in image processing. We explore different aggregation operators to aggregate the color information from an RGB image to identify the final edges. In this work we have focused on the classical Sobel and Canny algorithms that are applied over the RGB images and its grayscale versions. In order to evaluate the new color edge detection algorithm that we propose we have used the set of images from Berkeley and we have computed the precision, recall and F measures of the different approached. The way that color information -the different channels- are aggregated is proved to be relevant for the edge detection task.

4 - Fuzzy Extensions of the Dominance-Based Rough Set Approach
Marko Palangetić, Chris Cornelis, Salvatore Greco, Roman Slowinski

We propose some new possibilities of fuzzy extension of the dominance-based rough set approach (DRSA). DRSA generalizes the classical rough set theory where an equivalence relation is replaced with a dominance relation. It identifies inconsistencies with respect to the Pareto principle in ordinal classification data. Then, from data structured with DRSA into consistent and inconsistent part, a set of monotonic "if..., then..." rules is induced using algorithms called DomLEM and VC-DomLEM. A non-invasive transformation of non-ordinal classification data permits to use DRSA and monotonic rules also in this case. First we discuss ways to fuzzify the dominance relation and how such fuzzified relation may be used to extend the rule induction algorithms. Then we present the noise tolerant version of fuzzy DRSA, where the fuzzy DRSA is combined with the ordered weighted average (OWA) operator. Also in this case, we will present the implications of this fuzzy extensions of DRSA on the existing rule induction algorithms.

■ WA-47

Wednesday, 8:30-10:00 - L247

Nonsmooth optimization and applications 1

Stream: Continuous and Black Box Optimization
Invited session
Chair: Giovanna Miglionico

1 - Derivative-free nonsmooth optimization via approximate cutting-planes and proximity control
Giovanni Giallombardo, Manlio Gaudioso, Giovanna Miglionico

We introduce a bundle method for the unconstrained minimization of a nonsmooth function for which no subgradient information is available. In particular, we present an approximation mechanism of the subgradients that is based on enforcing, at each iterate-point stored in the bundle, the fulfilment of the subgradient inequality with respect to all other points. To this aim, two auxiliary optimization problems are considered, whose solution allows to generate a subgradient approximation. Such problems, a linear program and a strongly convex quadratic program, are involved in the approximation mechanism at every iterate-point, depending on both the relative geometrical configurations of the point with respect to the other ones, and on the specific role (serious-step vs. null-step) of the point in the bundle. In fact, the whole approximation mechanism is embedded into a bundle method for nonsmooth optimization, appropriately tailored to the derivative-free framework, for which we provide some convergence results along with a computational study on a set of academic test problems.

2 - Support vector machines for clusterwise linear regression
Kaisa Joki, Adil Bagirov, Napsu Karmitsa, Marko M. Mäkelä, Sona Taheri

In clusterwise linear regression (CLR), the aim is to simultaneously partition a data into a given number of clusters and find regression coefficients for each cluster. We will propose a novel approach to solve the CLR problem. The main idea is to utilize the support vector machines (SVM) approach to model the CLR problem by using the SVM for regression to approximate each cluster. This new formulation of the CLR problem is represented as an unconstrained nonsmooth optimization problem, where we minimize a difference of two convex (DC) functions. To solve this problem, a method based on the combination of the incremental algorithm and the double bundle method for DC optimization is introduced. Numerical results will be presented to validate the reliability of the new formulation for CLR and the efficiency of the proposed method. The results show that the SVM approach is beneficial in solving CLR problems, especially, when there are outliers in data.

3 - Support vector machines for piecewise linear regression with L1-norm
Sona Taheri, Adil Bagirov, Kaisa Joki, Napsu Karmitsa, Marko M. Mäkelä

In this talk, I will present a method that is developed to estimate regression functions using continuous piecewise linear functions. More precisley, the regression problem is formulated using L1-risk function, maxima of minima of linear functions representation of continuous piecewise linear functions and support vector machines for regression approach. This problem is reduced to an unconstrained nonsmooth nonconvex optimization problem where the objective function is presented as the difference of two nonsmooth convex (DC) functions. The double bundle method for nonsmooth DC optimization is combined with the incremental approach to design a method for solving the regression problem. The use of the incremental approach allows one to find good starting points so that the proposed method can compute global or nearly global solutions to the nonconvex regression problem. The proposed method is tested using several real-world data sets for regression and compared with mainstream regression algorithms based on machine learning approaches.

4 - Scaled Improvement Functions in Nonsmooth Multiobjective Bundle Methods
Marko M. Mäkelä, Outi Montonen

Improvement functions are used in nonsmooth optimization both for constraint handling and scalarization of multiple objectives. In the multiobjective case the improvement function possesses, for example the nice property that a descent direction for the improvement function improves all the objectives of the original problem. However, the numerical experiments have shown that the standard improvement function is rather sensitive for scaling. For this reason we present here a new scaled version of the improvement function capable not only for linear but also for polynomial, logarithmic, and exponential scaling for both objective and constraint functions. In order to be convinced about the usability of the scaled improvement function, we develop a new version of the multiobjective proximal bundle method utilizing the scaled improvement function. This new method can be proved to produce weakly Pareto stationary solutions. In addition, under some generalized convexity assumptions the solutions are guaranteed to be globally weakly Pareto optimal. Furthermore, we illustrate the affect of the scaling with some numerical examples.

■ WA-48

Wednesday, 8:30-10:00 - L248

Energy and Finance Models I

Stream: Mathematical Modelling
Invited session
Chair: Julia Grübel

1 - Common Property Management: Coalitions, Stock Effects and Congestion
Angels Xabadia, Renan Goetz

Collective action in the form of proceeds-sharing partnerships helps to balance the incentives for excessive effort from individuals or for free-riding among the members of the partnership. Within this context, previous literature has analyzed congestion costs and stock externalities separately. However, the correct formulation of the social optimum needs to consider that a) congestion and proceeds-sharing have to be disentangled and b) congestion costs and stock externalities are intertwined. In this way it is possible to choose different policy instruments that are specific to each externality-problem. If the interdependence of externalities is not contemplated, an evaluation of a policy instrument may result in being positive, when in fact the opposite is obtained with a detailed analysis. The interplay between proceeds-sharing, congestion costs and stock externalities is analyzed by using a two-step optimization formulation so that each effect can be isolated and policies can be specifically targeted. The study extends and generalizes previous results concerning the optimal size of partnerships and the necessary conditions for the equivalence between partnership solutions and the social optimum.

2 - Determining Extreme Events and Its Contribution in Increasing Accuracy and Flexibility of an Energy System Model
Phuong Khuong, Wolf Fichtner

Since 2014, EU has agreed on increase renewable energy share and grid interconnection rate by 2030, it requires urgently a multi-country Energy system model(ESM) for higher renewable penetration system with more flexibility and interconnection requirements. The requirements tightens the conflict between execution time, accuracy and resolution when designing ESM's time-structure. Therefore, finding an appropriate way to reduce time-slice but getting the most possible accuracy with minimum execution time is a big question in designing an advanced ESM. Past works have paid attention on representative load. In an attempt to estimate the whole demand distribution, they focus on the central part of the distribution and neglect the tails. The questions are raising are how important contribution of the tail events, which are low probability and large intensity, to the model output, may the events require the most attention regarding to flexibility and security, and do they help to increase the accurate of the model output, especially flexibility and security. Motivated by the unaddressed issues, this paper proposes a method dealing with the stochastic behavior of extreme values. It based on the idea of Extreme Value Theory with threshold approach to extract extreme events from residual load. Lastly, the paper proposes a method to assess the effect of different extremes based on different model's requirement by testing with an EU-EMS, called PERSEUS.

3 - On Electricity Market Equilibria with Storages: Modeling, Uniqueness, and a Distributed ADMM
Julia Grübel, Thomas Kleinert, Vanessa Krebs, Galina Orlinskaya, Lars Schewe, Martin Schmidt, Johannes Thürauf

We consider the spot-market trading of electricity including storage operators as additional agents besides producers and consumers. Storages allow for shifting produced electricity from one time period to a later one. Due to this, multiple market equilibria may occur even if classical uniqueness assumptions for the case without storages are satisfied. For the case with storage operators, we derive additional sufficient conditions that ensure uniqueness of generation and demand. We also prove uniqueness of the market equilibrium for the case of a single storage operator. Nevertheless, in case of multiple storage operators, uniqueness fails to hold, which we show by illustrative examples. We conclude the theoretical discussion with a general ex-post condition for proving the uniqueness of a given solution. In contrast to classical settings without storages, the computation of market outcomes is much more challenging since storage operations couple all trading events over time. For this reason, we propose a tailored parallel and distributed alternating direction method of multipliers for efficiently computing spot-market equilibria over long time horizons. We illustrate the practical performance of this method on large-scale and realistic data that cannot be handled with standard approaches.

4 - Uncertainty in non-deterministic processes: imprecise probabilities versus Nash equilibria
Joaquim Gabarro, Jorge Castro, Maria Serna

Antony Toni Hoare considers the non-deterministic "daemonic choice" operator between processes P and Q as a process which behaved like P or Q. Under the assumption that the selection is done without the knowledge or control of the external environment. Such a choice happens naturally when considering uncertainty in Web applications and in other settings.

We propose to cast the the uncertainty in a daemonic choice by imprecise probabilities as in [IPMU, 2018] or by generalizing the notion of "stress model" and angel-daemon games as in [IJDATS 9, 2017]. The second analysis goes through strategic games and Nash equilibria. We attempt to compare Nash equilibria and imprecise probabilities as a model for the daemonic choice. We apply this approach to study parametric models in economics like the IS-LM model and voting games.

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■ WA-49

Wednesday, 8:30-10:00 - L249

Software for large-scale optimization III

Stream: Software for Optimization
Invited session
Chair: Hassan Hijazi

1 - Parametric Optimization with the MPT Toolbox and its Applications in Optimal Control
Martin Klauco, Michal Kvasnica

The Multi-Parametric toolbox (MPT) is an open-source Matlab-based toolbox for parametric optimization, computational geometry, and synthesis of optimization-based controllers. It allows to formulate and solve parametric optimization problems where the objective is do find the analytical representation of the optimal solution as a function of a vector of parameters. For a broad class of problems the solution takes a form of a piecewise affine (PWA) function defined over a set of polyhedral regions. In this contribution we review recent advances in the field of parametric optimization with applications in optimal control design. Specifically, we report a novel enumeration-based algorithm that abolishes, to a certain extent, the main drawback of parametric programming, namely its bad scalability with respect to the dimension of the parametric space. This allows parametric optimization to be employed to synthesize optimization-based controllers even for large systems. Moreover, the algorithm features a storage-efficient compression of PWA functions originating from parametric optimization, allowing the parametric solutions to be implemented on a control hardware with modest resources. The theoretical development is supported by several practical case studies from the field of real-time model predictive control.

2 - On Convexifying Quadratic Constraints
Hassan Hijazi

In this talk, we will review recent advances in convexification approaches for quadratic constraints. This will include sparsity exploiting methods, semidefinite programming cuts, Lasserre's hierarchies and their implementation in the open-source modeling tool Gravity (https://github.com/coin-or/Gravity). Applications to the Optimal Power Flow problem will be presented.

3 - A new interior-point approach for large two-stage stochastic problems.
Paula de la Lama, Jordi Castro

Two-stage stochastic programming models give rise to very large optimization problems. Several approaches have been devised for its efficient solution, including interior-point (IP) algorithms. However, when using IP methods, linking columns associated to first-stage decisions cause an excessive fill-in in the normal equations, making the procedure computationally expensive. The reformulation of the linear programming problem through variable splitting techniques significantly reduced the solution time.

This work presents a specialized IP approach that exploits the structure of the extensive form formulation of the stochastic problem, once variable splitting has been applied. The specialized IP algorithm combines Cholesky factorizations and preconditioned conjugate gradient for the solution of the normal equations. It will be shown that, for stochastic programming problems with large enough first stages, our specialized approach outperforms standard IP methods in the computation of the Newton direction.

Computational results will be provided for two stochastic problems from the literature: (1) a supply chain system and (2) capacity expansion in an electric system. Both linear and quadratic formulations were considered, obtaining instances of up to 12 million variables and 6 million constraints. The computational results show that our procedure was more efficient than alternative state-of-the-art IP implementations (e.g. CPLEX) in those applications.

4 - Representation and solution of Stochastic Programming formulations in AMPL
Christian Valente, Gautam Mitra, Ansuman Swain

Over the last twenty years we have developed stochastic optimisation modelling tools, namely, SPInE and SAMPL which extended AMPL with constructs specifically designed to keep all the information about the model structure and pass it to the solver. The implementations involved pre-processing and specialised syntax for SP, CCP and ICCP models, which was limiting the degree of freedom we had in accessing/modifying the model itself. To gain full access to the declarative and procedural features available in AMPL, we have now developed templates and frameworks to describe this genre of models using native AMPL syntax; this approach conveys the structure to the generated instance. Combined with a customised solver driver, this permits an efficient solution of the classes of models above using FortSP, our SP and ISP solver, which we also present in a summary form.

■ WA-50

Wednesday, 8:30-10:00 - Mason Hayes & Curran

Methodological and practical contributions of Soft OR/PSMs to Policy Making - II

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: Irene Pluchinotta

1 - Uses an misuses of participation and deliberation framework in France
Juliette Rouchier

On 8 July 2002, France has ratified the Aarhus convention: participation and deliberation have become key mechanisms imposed by the regulation for each project dealing with public good. But so-called participation and deliberation processes have flourished in various locations and have contributed to mistrust in administrative processes. If we admit that deliberation and participation are not based on absolute principles but can be, in practice, framed and implemented differetly: they can lead to voluntary or involuntary misuses of some formal rules of public participation. In this paper we characterize and discuss what we consider to be biases, limits and dark sides of public participation strategies and methods. For this we draw a frame of analysis based on two French examples - the implementation of the Atmosphere' Protection Plan (PPA) in the Ile-de-France region in France (of which one author was part of the technical project team from January 2016 to April 2017 and the "Red Mud" case of an industrial pollution in south of France where the other author was part of several expertise groups and did some field research. The main problems identified are: participation and deliberation are seen as administrative constraints, shaping (number of people, sessions) is difficult, the impact of time passing, difficulty to to deal with opposing arguments and disagreements, needed neutrality and technical ability of facilitator and dilution of responsibility at the end.

2 - Integrating Problem Structuring Methods and Social Network Analysis for supporting risk management policy design and implementation: lessons learned from NAIAD project
Raffaele Giordano, Alessandro Pagano, Albert Scrieciu, Polona Pengal

Nature-Based Solutions (NBS) are increasingly adopted as measures for enabling climate change mitigation and adaptation, for reducing risks and for enhancing urban ecosystems. Nevertheless, several barriers are currently hampering the actual design and implementation of NBS for copying with water-related risks. Among those, the lack of effective methods for enabling the stakeholders' engagement in NBS design and implementation plays a key role. The activities described in this work had a twofold goal. On the one hand, efforts were carried out in order to enhance the communication toward the stakeholders and meet their actual information needs. On the other hand, the activities aimed at enhancing the effectiveness of the processes related to information sharing and communication. An approach based on the integration between Problem Structuring Methods (PSM) and Social Network Analysis (SNA) is described in this work. PSM were implemented in order to elicit and structure stakeholders' risk perception - i.e. individual perception of risk management goals and information requirements. SNA was implemented in order to identify the intervention (key) point in the network, according to the Network intervention approach. The results of the two methods were used to facilitate the NBS co-design through an effective stakeholders' engagement. This work describes the experiences carried out in three demo sites within the NAIAD project framework.

3 - Participatory methods mobilizing Soft OR/PSM approaches in water policy making processes
Olivier Barreteau, Emeline Hassenforder, Nils Ferrand, Raphaelle Ducrot

This contribution introduces the use of participatory methods mobilizing Soft OR/PSM approaches in water policy making. Water issues are wicked problems that require the use of Soft OR/PSM and the involvement of concerned stakeholders. We present methods aiming at supporting actors in contributing to the successive decision-making steps, from situation assessment to policy adaptation, through the identification of objectives, scenario exploration, options development, strategic planning and implementation. The methods we use belong to the CoOPLAaGE approach. They are based on participatory modelling of socio-environmental systems, strategic plans, governance trajectories, and decision-making processes. They mobilise stakeholder mapping, cognitive mapping, and causal mapping. Stakeholders are also involved in collecting data to support and analyse the policy making process. In other words, it is a participatory decision-aiding of, or monitoring and evaluation of, the participatory policy-making process. We will give concrete examples of the development of water policies where these participatory methods were used and analysed, in Bulgaria, France and New Caledonia. We argue that stakeholder participation throughout the policy cycle, in particular policy evaluation, is necessary for policies to be supported by social change and thus to have a socio-environmental impact. This poses methodological and practical challenges regarding the use of Soft OR/PSM that we will discuss.

4 - Policy co-design: integrating Problem Structuring Methods and Concept-Knowledge theory for generating policy alternatives
Irene Pluchinotta

Policy making that includes stakeholders offers best practices but also unsuccessful examples of case studies. Meaningful participation requires direct integration of stakeholders into all the phases of the public decision-making process in order to unleash innovation. Recurrently, policy making incorporates participation late in the process, after the problem definition has occurred, alternatives have been defined, without considering stakeholders' knowledge and problem understanding. Within this context, there is a demand for methodologies aiming to support policy makers and relevant stakeholders during the design of policy alternatives. However, the formal process of policy alternatives generation has been little investigated. The talk introduces the operational role of Design Theory, and specifically Concept-Knowledge (C-K) theory, for the co-design of policy alternatives. This work describes a methodology based on integration between Problem Structuring Methods (PSMs) and C-K theory-based tool, as enabling factor of collective policy-making process. PSMs, and specifically Fuzzy Cognitive Maps, are implemented to elicit and structure individual problem understandings, to detect and analyse differences among different stakeholders' concerns and values. C-K theory framework is then meant to facilitate the alignment of the different problem frames and available knowledge and to enable the creative process for developing innovative and consensual policies.

■ WA-51

Wednesday, 8:30-10:00 - William Fry

Innovative Real Investments

Stream: Optimal Control Theory and Applications
Invited session
Chair: Andrea Seidl

1 - Optimal investment in CO2 reducing technologies: CO2 tax versus EU-ETS
Tine Compernolle, Peter M. Kort, Jacco Thijssen

An increasing concern for climate change puts pressure on industrial firms to implement practices for carbon emission reductions. Recent literature seems to indicate that a CO2 tax is preferred over an emission trading system to stimulate the adoption of CO2 reducing technologies. We compare a CO2 tax system with an emission trading system to analyze the decision to invest in technologies that differ in terms of CO2 emissions.

Under a CO2 tax system, there is only one uncertain price process: the revenue that results from selling the economic output. The cost flow of the CO2 produced is constant. Under the emission trading system however, both the price process of the economic output and the CO2 cost are stochastic. An investment problem with two stochastic price processes can only be solved analytically if no other constant parameters are involved and if the gain function is homogeneous of degree one. We therefore, build a model that has this feature, so that we can solve for the optimal investment policy analytically, both in the case of a CO2 tax and a stochastic, market-driven CO2 price.

We show that in the light of uncertainty, the CO2 tax is not always the preferred policy instrument to stimulate investment in CO2 reducing technologies.

2 - Lump-sum capital investment under uncertainty: the effect of depreciation on innovation
Nick Huberts, Rafael Rossi Silveira

This paper considers the investment problem of a monopolist that faces depreciation of its capital stock that cannot be continuously offset. It has the option to innovate by investing in a one-off lump-sum investment. The firm decides upon the optimal level of the capital stock and determines the optimal investment moment. In the first version of this model the production technology for the additional capital stock yields improved productivity. We show that, under certain conditions, larger rates of depreciation delay the implementation of the new technology. The second version of the model considers the firm's innovation option when it can reduce, at least partially, the rate of capital depreciation.

3 - Innovation Investment under Bankruptcy Risk
Xingang Wen, Herbert Dawid

This paper presents a dynamic model of a firm which can invest in technology to produce a new product (a partial substitute for the current old product) with uncertain demand. The product innovation success enables the firm to be active in both markets. A financial constraint is introduced such that a firm with negative liquidity has to exit the market with a certain probability if it cannot service its debt, i.e., bankruptcy risk. Liquidity evolves over time based on the profit on the established market net of dividends, as well as the costly R&D investment and interest payments. A numerical method is used to calculate the firm's value functions in different modes (pre- and post-innovation) and states (positive and negative liquidity), taking into consideration the mode and state transitions. Moreover, the paper analyzes the firm's optimal investment and the influence of financial constraint on the firm's liquidity dynamics.

4 - Opening the source code: the threat of forking
Andrea Seidl, Stefan Wrzaczek

Making software open-source can have substantial positive effects on the quality and the diffusion of a software and strengthen the sales of complimentary products. However, it is a large concern of firms that the free accessibility of their source code is against the own interests: a competitor might use the very same source code to start its own competitive project, a so-called fork. In the present paper we analyze whether the threat of forking prevents a firm to open its source code. Therefore, we consider three different regimes: In the first regime a firm develops and sells software under a proprietary license, in the second regime, it uses an open-source business model. The third regime is characterized by the competition with a second firm with a forked software project. Whether and when there is a switch from the first to the second regime is optimally determined by the original developer of the software, the competitor optimally decides whether and when it pays off to enter the market. We find that a high software quality is not always beneficial for a firm wanting to enter the market with a fork as it gives the original software developer an incentive to keep the software under a proprietary license. Furthermore, if the fork cannot sufficiently take advantage of the original software's quality, a high quality gives the market incumbent a strong competitive advantage with respect to attracting customers and contributions from the open-source community.

Wednesday, 10:30-12:00

■ WB-01

Wednesday, 10:30-12:00 - O'Reilly Hall

Roberto Cominetti

Stream: Tutorials
Tutorial session
Chair: Patrizia Daniele

1 - Routing games in congested networks: convergence for large games and the Price-of-Anarchy
Roberto Cominetti

We revisit the concept of Wardrop equilibria for routing games, as a continuous approximation for finite games with an increasing number of small players. We consider two scenarios: a deterministic model in which players have a small weight, and also a stochastic scenario in which players have non-negligible weight but are present with a small probability. In both cases we provide a formal proof of convergence towards two different Wardrop models, where in the second case the flows in the network retain their stochastic nature and are described by Poisson distributions. We also discuss some recent results regarding the behavior of the Price-of-Anarchy under these different regimes, both at intermediate levels of congestion as well as in the limit when the network becomes heavily congested.

■ WB-03

Wednesday, 10:30-12:00 - Q106

Tutorial: Optimizing with Python

Stream: Practice of OR (Making an Impact)
Tutorial session
Chair: Joaquim Gromicho

1 - Tutorial: optimizing with python
Joaquim Gromicho

Academics in OR learned a multitude of programming and modeling languages, all with their strong and weak points. Nowadays general purpose languages exist and python seems to dominate on all domains of analytics, but how good is it for optimization? That is exactly what this tutorial will teach you, taking into account mathematical modelling and optimization and also the development of heuristics for hard and challenging problems.

■ WB-06

Wednesday, 10:30-12:00 - A004

Modelling & Algorithms for Energy Systems

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Paula Carroll

1 - Analysing Potential Flexibility Resources for Future Integrated Power Systems within Unit Commitment Optimisation
Ran Li, Damian Flynn, Paula Carroll, Juha Kiviluoma, Ciara O'Dwyer, Dana Kirchem, Niina Helistö

With an increasing share of renewables in future power systems, there is growing interest in utilising the inherent flexibility of other energy networks, e.g. water, gas, heating, to directly enhance power system flexibility. Hence, an integrated unit commitment model has been developed, using mixed-integer programming, under a stochastic framework to deal with forecast uncertainty. In the model, the power system consists of 3 major components: grids, which are networks of the same energy type (water, gas, electricity); nodes, where load, reserve and exogenous flows (wind, solar, etc.) are placed, and an energy balance must be reached; units, real or virtual, that convert one form of energy to another, using a conversion relationship, e.g. efficiency, heat rate. Flexibility resources, e.g. electric vehicle charging load, can be attached at individual nodes, with a unit transferring energy from the electricity network to a separate battery (energy storage) node, enabling the power system to gain flexibility through demand shifting. Similarly, by modelling the water network, the of waste water treatment processes can be scheduled to assist power system flexibility. The model can be applied to both operational and long-term system planning timeframes, and it can analyse the value of different flexibility resources, e.g. heat demand (temperature), EV driving demand, power to gas (gas network), based upon real-world data, and the planned future power system portfolio of Ireland.

2 - Benders decomposition with adaptive oracles for power system planning with renewables
Nicolò Mazzi, Andreas Grothey, Ken McKinnon

We propose an algorithm to efficiently solve large power system capacity expansion problems which exhibit a column bounded block-diagonal structure, where subproblems differ in right-hand side and cost coefficients. Similar optimization problems are usually tackled using cutting-plane algorithms, which allow for an iterative and decomposed solution of the problem. When solving subproblems is computationally expensive and the set of subproblems is large, cutting-plane algorithms may slow down severely. In this context we propose two novel adaptive oracles that yield inexact information, potentially much faster than solving the subproblem. The first adaptive oracle generates inexact but valid cutting planes, and the second adaptive oracle gives a valid upper bound of the true optimal objective. These two oracles progressively "adapt" towards the true exact oracle if provided with an increasing number of exact solutions, stored throughout the iterations. These adaptive oracles are embedded within a Benders-type algorithm able to handle inexact information. We compare the Benders with adaptive oracles against a standard Benders algorithm on a stochastic investment planning problem for power system capacity expansion with renewables. The proposed algorithm substantially reduces the computational effort to solve the problem up to a predefined convergence tolerance. An illustrative case is 32 times faster for a 1.00% tolerance and 10 times faster for a 0.01% tolerance.

3 - Multi-objective multi-period optimal congestion management in the transmission grid
Manuel Ruppert, Armin Ardone, Wolf Fichtner

Increasing shares of intermittent renewable generation in electricity systems are changing the existing system's topology and pose a new challenge for congestion management in the transmission grid. In markets with a decoupled process of generation dispatch and electricity grid operation, raising average distance between generation and demand leads to a higher amount of congestion which has to be resolved with congestion management. This results in more market adjustments by thermal power plant redispatch and curtailment of renewable generation. Subsequently, system inefficiencies, expenditures, and greenhouse gas emissions are raising.

To address this issue, a multi-objective, multi-period nonlinear optimal power flow approach for congestion management has been developed. This approach accounts for the deviation from the market result, as well as additional system cost and emission caused by congestion management and was applied to the market area of Central Western Europe and Switzerland. The results of the congestion management optimisation in a significantly congested system show that the multi objective solution accounting for all dimensions has substantial advantages in comparison to the optimisation towards a single objective function. Furthermore, the multi-period formulation allows for the inclusion of storage units during connected congestion events and leads to a further reduction in all three objective dimensions.

■ WB-07

Wednesday, 10:30-12:00 - A007

DSS Applications

Stream: Decision Support Systems
Invited session
Chair: Pascale Zaraté

1 - Improving an agent based model of electric vehicle adoption using machine learning technologies
Wen Xu, Irina Harris

Agent based modelling can capture interactions and consumer heterogeneity in decision making process and thus gains popularity in innovative adoption research.Evidences show that current models failed to capture how electric vehicles (EVs) penetrated the market, and appear to have an overly optimistic view of adoption rates. This is due to that consumer adoption behaviours are oversimplified and the factors being integrated into the decision rule cannot capture consumer heterogeneity, identified by a systematic literature review. This work applies machine learning technologies to improve the limitations, through an analysis of the private adoption of EVs in the UK. Firstly, survey data on consumer priorities for vehicle purchase are pre-processed. Then several machine learning algorithms are conducted to classify consumer groups such as EV innovators and laggards. The algorithm with the highest prediction accuracy is selected as purchase decision rule. Finally, an agent based model of EV adoption is built to model consumer decisions on whether and when to buy an EV and which vehicle model within the predefined choice set to buy, based on the purchase probability calculated by C5.0. Results identify that machine learning technologies can be applied to capture consumer heterogeneity in agent based modelling, through helping identify the import factors for purchase decision, select algorithm as decision rule, and justify the influencing degree for social interactions.

2 - Mathematical modelling approaches in a specialised learning management system towards improved academic performance feedback
Annette van der Merwe, Tiny Du Toit, Hennie Kruger

Comprehensive and dynamic academic feedback has the potential to considerably improve the student retention rates at universities while empowering students to better self-regulate their learning. Such feedback contains information that reports on the current academic performance of students (feed backwards) and provides individualised improvement goals (feed upwards) as well as provisional objectives for reaching ultimate improvement goals (feed forwards). Different mathematical modelling approaches, including non-linear programming models, a data envelopment analysis model, the analytic hierarchy process, linear programming models and a decision tree approach, were employed to emulate and improve on existing academic performance calculation techniques. Specialised algorithms that implement a linear programming model, a non-linear programming model and a decision tree approach, were developed and implemented in a computerised demonstrator. The program was ultimately deployed and evaluated in a specialised learning management system at a tertiary education institution. Findings showed a very high degree of student satisfaction, improved program management by lecturers and institutions, accurate decision support in learning analytics and enhanced communication between institutions and students.

3 - A framework approach to bridge the gap between decision-making and IoT infrastructure
Lien Wang, Rongjia Song, Jan Vanthienen

The Internet of Things (IoT), coupled to intelligent data analytics, is the preeminent cornerstone technology for aligning decision-making and business processes to data, that could help to make better-informed and context-aware decisions. IoT devices are emerging data sources of system behaviours and external environments for dynamic data analytics to obtain the context-awareness of the operation. Recently, the Decision Model and Notation (DMN) standard provides a solution and technique to model decisions and processes separately and consistently integrated. The DMN technique supports the ability to extract and operationalize the value from data analytics since the value of data analytics lies in improving decision-making. In light of this research trend, this paper proposes the following research question: "How can the decision-making in business processes be IoT-enhanced?". A framework is presented to connect the decision-making of business processes with IoT infrastructure through IoT-enhanced decision support models and IoT-aware data analytics models. IoT data provides smart support for the business knowledge of the operation. This paper also presents a study in the scenario of IoT applied harbour operations that applies the proposed framework. The study results reveal that the framework is an effective approach for improving the understanding of how to leverage smart data to support the decision-making of business process in the IoT paradigm.

■ WB-08

Wednesday, 10:30-12:00 - A008

Applications of Stochastic Optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: Patrizia Beraldi

1 - A Stochastic Multi-period Transshipment Selection Problem with Synchronized Handling Operations
Riccardo Giusti, Daniele Manerba, Roberto Tadei

In the Transshipment Selection Problem, we want to select transshipment facilities (e.g, inter-modal hubs) to transport freight from origins to destinations such that a given total transportation utility is maximized. However, to consider flexible and reliable networks within the most advanced synchro-modal supply-chains, flow synchronization at facilities must be ensured. Clearly, synchronization depends on a large set of unknown events (lateness of transportation, slow execution of handling operations, service interruptions, etc.). Therefore, the selection of transshipment facilities must be done under uncertainty. In fact, congestion, significant containers leftover, and loss of connections could cause both unexpected reductions of facilities capacity (over time horizons) and stochastic handling utilities. Hence, we introduce a stochastic and multi-period variant of the Transshipment Selection Problem in which uncertainty of facility capacity and handling utilities are both considered. We aim to select transshipment facilities and to allocate freight flows to maximize the expected total net transportation utility. We propose a two-stage Stochastic Programming (SP) formulation with recourse and calculate several standard SP measures (VSS, EVPI, LUSS, LUDS) to assess our modelling framework. Finally, given the computational burden to solve exactly this model for real-life instances, some heuristic approaches will be presented, and their performance carefully tested.

2 - A Stochastic Programming Approach for the Energy Prosumer Management Problem
Patrizia Beraldi, Antonio Violi, Massimiliano Ferrara, Maria Elena Bruni, Marco D'Ambra

In recent years, the energy sector is facing unique challenges that are reshaping the way energy is produced, transported and distributed. As part of this evolution, the role of the end user is changing, and consumers are increasingly producing energy, typically from renewable energy sources. These new users, termed as prosumers, have the opportunity to meet significant portions of their own energy needs and to eventually sell the excess power to the network. The talk focuses on the problem faced by a prosumer in the optimal management of the available energy resources, i.e. PV panels and storage systems, with the aim of satisfying the own demand and minimize the overall procurement costs. We assume that the use of some devices can be shifted within predefined time windows, as, for example, washing machines and/or charging of electric vehicles. The problem is made more challenging by the presence of uncertainty, coming from a variety of sources including the weather condition, influencing the production from renewables, the consumer behavior and the dynamic electricity prices. To properly account for uncertainty, a two stage stochastic programming problem is modelled and solved for different categories of residential prosumers. The preliminary computational results have shown the effectiveness of the proposed approach especially when adopted to manage aggregations of prosumers, where multiple users work in a coordinated manner in order to achieve the maximum benefit.

3 - Preference selection of Lithuanian II pillar pension funds by stochastic dominance rules
Audrius Kabasinskas, Milos Kopa, Kristina Sutiene

Presentation contributes to the research of multi-pillar pension system, mainly focusing on the private pension funds. In this context, the specific objective of this study is to determine which private fund in the second pillar is the best for a participant on the basis of his risk profile. Depending on the assumption on the pension system participant's utility function, the four different types of stochastic dominance (SD) relations are considered, specifically first-order, second-order, third-order and SD generated by utility functions with decreasing absolute risk aversion. We provide the analysis under three distributional assumptions: empirical, stable and truncated $alpha$-stable distribution of returns. Moreover, for non-dominated funds, an investor for which the fund is the optimal choice is identified. Allowing diversification the efficiency of the pension funds with respect to several types of SD is tested. Finally, the behaviour of the participants in last quarter/year is compared to the results of SD analysis. Despite focusing on Lithuanian pension funds, the methodology developed might be employed by a participant or pension fund manager in similar markets of other countries as well.

4 - Multistage stochastic dominance: an application to pension fund management
Sebastiano Vitali, Milos Kopa, Vittorio Moriggia

A pension fund manager typically decides the allocation of the pension fund assets looking for a long term sustainability. Many Asset and Liability Management models in the form of multistage stochastic programming problem have been proposed to help the pension fund manager to define the optimal allocation given a multi-objective function. The recent literature proposes multistage stochastic dominance constraints to guarantee that the optimal strategy is able to stochastically dominate a benchmark portfolio. In this work we extend previous results to another type of stochastic dominance that appears more consistent to use in a multistage framework. Indeed, instead of considering multiple single-stage stochastic dominance constraints, we apply a unique constraint that involves jointly multiple stages. Numerical results show the difference between the different ways to interpret and apply the multistage stochastic dominance.

■ WB-09

Wednesday, 10:30-12:00 - B006

Performance Measurement IV

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: Riccardo Cambini

1 - Apportionment methods in resource allocation
László Kóczy, Tamás Koltai, Balázs R. Sziklai, Alexandra Tamás

The efficient use of resources is of paramount importance in any organisation and this is especially true for the use of human resources. We are considering an organisation that operates with a fixed number of positions over a network of subunits. The relative efficiency of these units can be uncovered using Data Envelopment Analysis (DEA) methods (Charnes, Cooper, Rhodes, EJOR 1978; for a recent application see Koltai, Lozano, Uzonyi-Kecskés, Moreno, CIE, 2017). How to overcome efficiency differences when resources are constrained? Motivated by concerns for quality assurance we use a method that lexicographically minimizing the tasks per worker. We present a fast algorithm to calculate the optimal allocation. Connections to the apportionment literature - mostly focusing on the fair allocation of voting districts among geographical or administrative regions (Balinski, Young, 1982; Pukelsheim, 2014, Biró, Kóczy, Sziklai, MSS, 2015; Kóczy, Sziklai, ORL, 2018), - are discussed. The allocation can be validated using DEA: efficiency indicators are now levelled.

The method is illustrated using data over salary administrators at Hungarian State Treasury's 19 county level subsidiaries. Knowing the number of standard administrative tasks for each subsidiary and for each month we allocate workers proportionally to the busiest months. After the reallocation the relative efficiency of the worst performing counties moves from about 60% to over 90%.

2 - Vea and targeted benevolence cross efficiency
Panagiotis Ravanos, Giannis Karagiannis

The aim of this paper is to explore the relationship between the Targeted Benevolence (TB) secondary goal model for cross efficiencies estimation, and Value Efficiency Analysis (VEA). The TB formulation gives to each DMU the benefit-of-the-doubt to select the individual best among possible multiple optima existing for each of its peers, but comes with a high computational burden preventing its widespread use among practitioners: Each different cell of the cross efficiency matrix needs the estimation of a different linear program. The equivalence between TB formulation and VEA provides shortcuts to the estimation of Targeted Benevolence cross efficiency: it permits the estimation of fewer linear programs, each with fewer constraints, as we may conduct peer evaluation by means of cross efficiency based solely on the envelopment form of the model. The cross-efficiency matrix is estimated utilizing the DMU's different reference sets as most-preferred-solutions (MPS) in VEA models. We provide an empirical application using a dataset of Greek cotton farms for the crop year 2000-2001.

3 - A partitioning method for a class of Rank2 problems
Riccardo Cambini

Rank2 problems are nothing but nonlinear minimization problems over polyhedrons where a linear transformation of the variables provides an objective function which actually depends on just 2 variables. These problems appear quite easily in applications, for example in location-allocation models, Data Envelopment Analysis, multiobjective/bicriteria programs. The particular structure of the problem allows to determine a partitioning solution method based on very tight underestimation functions and hence having very good algorithmic performances.

■ WB-11

Wednesday, 10:30-12:00 - H1.12

Bilevel Optimization in Energy

Stream: Mixed-Integer Nonlinear Programming
Invited session
Chair: Mathieu Besançon
Chair: Martine Labbé
Chair: Bernard Fortz

1 - A Bi-Level Optimization Formulation of Multilevel Demand Subscription Pricing
Yuting Mou, Anthony Papavasiliou, Philippe Chevalier

In this study, we revisit a multilevel demand subscription pricing policy (MDSP) for electric power, in which a price plan to assign different reliability combined with duration for a slice of power is offered. The reliability component in the price menu is motivated by variations in renewable energy supply. Lower reliability corresponds to a lower capacity charge, which motivates consumers to mobilize their flexibility in electricity consumption. The duration component is regarded as the amount of 'credits' that consumers purchase for this slice of power. The established theory for menu design is based on numerous stringent assumptions, which may not be respected in practice, such as well-behaved (convex) cost functions. In addition, the objective of the menu design is to maximize social welfare, while the profit requirement of the aggregator is not accounted for. We formulate the MDSP menu design problem as a Stackelberg game where an aggregator moves first with a menu offering, and residential consumers react by selecting menu options, revealing their valuation. The Stackelberg game is modelled as a bi-level optimization problem involving the aggregator and consumers, and then reformulated as a mixed-integer problem. Using our approach, we are able to integrate the menu design problem into a day-ahead market model. The approach is illustrated on a toy numerical example as well as a large-scale model of the Belgian power market.

2 - Strategic bidding in Price Coupled Regions
Jérôme De Boeck, Luce Brotcorne, Bernard Fortz

The classical Unit Commitment problem (UC) can be described as the problem of establishing the energy output of a set of generation units over a time horizon, in order to satisfy a demand for energy, while minimizing the cost of generation and respecting technological restrictions of the units. Traditional models for the UC assume that the net demand for each period is perfectly known in advance. However, in practice, the demand is dictated by the amounts that can be sold by the producer at given prices on the day-ahead market. We consider Price Coupling of Regions (PCR) as bidding market, a coupling linking national day-ahead markets in order to increase the global welfare.

Our aim is to solve the UC problem with a second level of decisions ensuring that the production is cleared at market equilibrium, leading to a bilevel optimization problem. In their simplest form, market equilibrium constraints are equivalent to the first-order optimality conditions of a linear program. The UC in contrast is usually a nonlinear problem that is linearized and solved with traditional mixed integer programming (MIP) solvers.

Following the classical approach for these models, we present the transformation of the problem into a single-level program by rewriting and linearizing the first-order optimality conditions of the second level. A discretization of the optimal spot prices is made and valid inequalities are proposes to obtain a tight MILP formulation.

3 - Near-optimal bilevel optimization and applications to the Time-and-Level-of-Use pricing
Mathieu Besançon, Miguel F. Anjos, Luce Brotcorne

Bilevel optimization is a class of mathematical optimization problems that include a lower level optimization problem in the constraints. We develop the near-optimal version of bilevel optimization, corresponding to the anticipation of a bounded rationality decision-maker at the lower level, or accepting a given deviation from the optimum. We show that this near-optimal version is a generalization of the pessimistic bilevel problem, and in particular of the variant introduced by Wiesemann et al. (2013, SIAM J. Opt.). We derive a solution method for some cases of near-optimal bilevel problems, building on results from both bilevel and robust optimization. We present an application to the optimal pricing of a Time-and-Level-of-Use tariff for demand response in power systems, with the supplier choosing the pricing components while ensuring the respect of network and generation constraints.

■ WB-12

Wednesday, 10:30-12:00 - H1.51

Decision Support Systems and Combinatorial Optimization

Stream: Combinatorial Optimization I
Invited session
Chair: Manuel Iori

1 - A Decision Support System for Attended Home Services
Filippo Castegini, Bruno Bruck, Jean-François Cordeau, Manuel Iori, Tommaso Poncemi

This work describes a decision support system to address a practical attended home services problem faced by Gruppo Iren, an Italian distributor of electricity, gas and water. The company operates in several regions across Italy and must optimize the dispatch of technicians to customer locations where they carry out installation or maintenance activities within time slots chosen by the customers. The system uses historical data and helps managers to divide regions into clusters based on the minimum travel time among towns, to create weekly time slot tables for each cluster and evaluate them dynamically within a rolling horizon approach, and to simulate and visualize optimal technician routing plans in order to analyze results under different scenarios. The system uses a previously developed integer linear programming tool to specify the amount of resources allocated to each region in each time slot and to route technicians in a cost-effective way. This tool has been modified to fit new quality of service constraints and to design an automated instrument for solving multiple-tasks problems. Computational experiments carried out on data provided by the company confirm the efficiency of the proposed methodology.

2 - A Decision Support System to Evaluate Suppliers in the Context of Global Service Providers
Dario Vezzali, Bruno Bruck, Manuel Iori, Daniele Pretolani

In this work, we propose a decision support system (DSS) to evaluate a set of suppliers by considering a multiplicity of variables. The DSS has been implemented to solve a real problem faced by a Global Service Provider (GSP) operating in the Italian market, and is based on a simplified Analytic Hierarchy Process (AHP) application. GSPs operate in the field of facility management, providing customers with general maintenance services for their real estate assets. To realize this purpose, they subcontract to selected suppliers the execution of services. A comprehensive and multi-criteria evaluation of suppliers is the key element to select the most fitting one for a specific service requested by a particular customer. This process of suppliers' selection directly affects success and duration of the relationship between the GSP and its customers. The content of our work consists of five parts: first, variables identification and description, necessary to create an objective and comprehensive evaluation of GSP's suppliers; second, weights calculation of defined variables accordingly to the AHP method; third, mathematical model formulation in order to precisely describe the decision problem; fourth, data collection and database creation containing all of the raw data necessary to perform the evaluation; fifth, DSS development and test with potential users through a web application prototype specifically developed for the problem.

3 - A Decision Support System for Storage Allocation in the Field of Pharmaceutical Distribution
Giorgio Zucchi, Manuel Iori, Nilson Felipe Mendes, Giovanni Vitorassi Moreira

In warehouses where the flow of stock keeping units (SKUs) is intense and diversified, the process of picking items is one of the main sources of logistic costs. To deal with this, decision makers must constantly consider questions related to storage constraints, request priorities, pickers routes, SKU demand seasonality and even human behaviour.

Our research deals with a major problem in this area, called Storage Allocation Problem. It consists in assigning products to cells of a warehouse so as to minimize the total picking distance. We base our study on a real scenario in the field of pharmaceutical distribution that has been provided by Coopservice, a major Italian logistic company.

The main contribution of our work is provide a robust data-driven algorithm that receives in input the warehouse structure and a huge database of the performed SKU picking lists, and finds a good-quality solution by means of an Iterated Local Search (ILS). The ILS swaps SKUs assigned to different cells initially defined in a greedy way, and evaluates the quality of new solutions by approximately solving TSPs for entries in the pool of picking lists. Computational tests indicate that a basic MILP model works only on very small instances, whereas the ILS is effective and improves consistently the solutions obtained by the initial greedy heuristic. The algorithm has been embedded into a Decision Support System equipped with a user-friendly graphical interface.

4 - Efficient and sustainable waste collection
Vera Fischer, Reinhard Bürgy, Bernard Ries

In most Swiss municipalities, a curbside system is used to collect the non-recoverable waste. Typically, garbage bags are placed on the sideways of the streets, and rear-loaded trucks collect them at a specific day of the week. Due to the many stops of the heavy trucks, this classic waste collection strategy causes high fuel consumption, emissions and noise. The objective of our project is to design innovative, sustainable waste collection concepts, as for example multi-level systems with intermediate depots, and to develop mathematical models and optimization methods to optimally match a waste collection concept to a given municipality. Resulting key figures and an interactive decision support tool will help decision makers to choose the best concept for their municipality. In this talk, we present the general setting of our project and our first modeling steps, in which we consider a single-level waste collection problem. It consists of selecting waste collection points, where households can deposit their waste, and defining routes for its collection. We aim at minimizing the total cost under various practically relevant constraints. We include costs for opening collection points and for travel distances associated to bringing the waste to the defined points by foot and collecting it from there by vehicles.

■ WB-13

Wednesday, 10:30-12:00 - H2.12

Continuous Optimization

Stream: Continuous Optimization (contributed)
Contributed session
Chair: Milan Hladik

1 - Optimality Conditions for Nonconvex Variational Problems with Integral Constraints in Banach Spaces
Nobusumi Sagara

The purpose of this paper is to exemplify that saturation is an indispensable structure on measure spaces to obtain the existence and characterization of solutions to nonconvex variational problems with integral constraints in separable Banach spaces and their dual spaces. The state constraints are formulated in the Bochner and Gelfand integral settings with control systems in separable metrizable spaces. The problem under consideration is a general reduced form of the isometric problem, which is an infinite-dimensional analogue of Aumann–Perles. We provide a characterization of optimality via the subgradient like inequality for the integrand and the state constraint function, which describes the maximum principle for the Hamiltonian. We prove an existence result without the purification of relaxed controls, in which the compactness and convexity of the integral of an multifunction with values in infinite dimensions under the saturation hypothesis on the underlying measure space plays a crucial role. We also demonstrate that the existence of solutions for certain class of primitives is necessary and sufficient for the measure space to be saturated, which provides another characterization of saturation.

2 - 3 for the price of 2: On higher order methods for system of nonlinear equations
Trond Steihaug

In this talk, we consider solving nonlinear systems of equations and unconstrained optimization using methods with convergence rate 2 and 3. Methods in Halley class have in general local and third order rate of convergence while Newton's method has quadratic rate of convergence. Third-order methods will, use fewer iterations than a second-order method to reach the same accuracy. However, the number of arithmetic operations per iteration is in general higher for third-order methods than for a second-order method. We will demonstrate that for a large class of problems, the ratio of the number of arithmetic operations of Halley's method and Newton's method is constant per iteration (independent of the number of unknowns).

In the unconstrained optimization case, the Halley methods will require the second and third derivative. We say that the sparsity pattern of the third derivative (or tensor) is induced by the sparsity pattern of the Hessian matrix. We will discuss some datastructures for matrices where the indices of nonzero elements of the tensor can be computed. Historical notes will be merged into the talk.

3 - Several tests for recognizing pseudoconvexity on a restricted domain
Milan Hladik

Pseudoconvexity of real functions is a generalized concept of convexity. Pseudoconvex objective functions have some nice properties in the context of optimization: On the convex feasible set, each stationary point is a global minimum point, each local minimum is a global minimum, and the optimal solution set is convex.

We consider the problem of checking pseudoconvexity of a twice differentiable function on an interval domain (hyper-rectangle), or more generally, on a zonotope. Based on several characterizations of pseudoconvexity of a real function, we propose sufficient conditions for verifying pseudoconvexity. Our approach utilizes not only interval arithmetic, but also more accurate affine form enclosures and affine arithmetic. We modify the tests to work with linear interval parametric enclosures of the gradients and the Hessians. We also present computational complexity results, showing that performing some tests exactly is NP-hard. It is shown by numerical experiments on random and benchmark data how the methods perform from two perspectives - the computational complexity and effectiveness of recognizing pseudoconvexity.

■ WB-14

Wednesday, 10:30-12:00 - H2.20

MIP Applications II

Stream: Mixed Integer Programming
Invited session
Chair: Tom Walther

1 - MILP-Based Algorithm for the Global Solution of Dynamic Economic Dispatch Problems with Valve-Point Effects
Loïc Van Hoorebeeck

The Dynamic Economic Dispatch (DED) problem consists in satisfying a certain demand for electric power among scheduled generating units over a certain interval of time while satisfying the operating constraints of these units. The consideration of the valve-point effect (VPE) makes the problem more practical but also more challenging due to the non-linear and non-smooth constraints that are required for representing the model. We present a method, based on a sequence of piecewise linear approximations, which produces a feasible solution along with a lower bound to the global solution. In this way, this deterministic approach can trade off the speed which characterizes certain heuristics that are usually used to solve the DED-VPE for a better solution and insights about the problem. The method is applied to a widely used case study and provides a lower solution objective than the best-known solution to date.

2 - An MIP formulation for multi-asset batch auctions with uniform clearing prices
Tom Walther

In traditional continuous-time asset exchange mechanisms, limit orders are typically collected in order books of two assets that are traded against each other. A trade happens whenever a buy order of one asset is met by a matching sell order. In a setting of multiple tradable assets, one separate order book is required for every asset pair, which limits its liquidity for less frequently traded asset pairs and enables arbitrage opportunities across asset pairs for professional traders.

By contrast, in our approach, we collect orders for a set of multiple assets in a single joint order book and compute exchange prices for all asset pairs simultaneously at the end of discrete time intervals ("multi-asset batch auction"). Trades between the same asset pairs are then all executed at the same exchange rate ("uniform clearing price"). This mechanism enables so-called ring trades, where orders are matched along cycles of assets. Prices are required to be coherent, i.e., the exchange rates along every such cycle of assets must multiply up to 1.

In this talk, we will present a MIP formulation for computing uniform clearing prices in our multi-asset batch auction scenario, show some computational results with particular focus on the influence of valid inequalities that can be incorporated, and give context on practical applications as well as an outlook on future extensions.

3 - Single Item Lot Sizing Problem for Flow Shop Environment with Multiple Energy Sources
Melek Rodoplu, Taha Arbaoui, Alice Yalaoui

The principal purpose of a typical production system is to satisfy the external demand by minimizing the production costs. To define the optimum production quantity that can satisfy the external demand by respecting the system constraints has always been an attractive area for the researchers and addressed as lot sizing problem. To sustain the production activity as it is planned, the required energy must be supplied without any deduction. To provide the demanded power to their customer without any interruption and protect their energy generation facilities from the problems that might cause from the high fluctuations in power demand, energy providers need to plan their energy generation and transmission process in an efficient way. To do so, knowing the power demand of their customers in advance has a crucial importance. For this purpose, they offer energy tariffs and power contract options to their customers. In our study, we combine the single item lot sizing problem in flow shop environment with the optimum energy contract selection problem by considering renewable energy sources. To best of our knowledge, our study is the first attempt which builds a bridge between required power demand and the contract options offered by the energy supplier. To solve the problem, a Mixed Integer Programming (MIP) model is developed to identify the best energy contract option and the optimum production sizes for a manufacturing facility.

4 - On the balanced minimum evolution polytope
Daniele Catanzaro, Laurence Wolsey, Raffaele Pesenti

Recent advances on the polyhedral combinatorics of the Balanced Minimum Evolution Problem (BMEP enabled the characterization of a number of facets of its convex hull (also referred to as the BMEP polytope) as well as the discovery of connections between this polytope and the permutoassociahedron. We extend here these studies, by presenting new results concerning some fundamental characteristics of the BMEP polytope, new facets defining inequalities in the case of six or more taxa, a number of valid inequalities, and a polynomial time oracle to recognize its vertices. Our results contribute to broaden understanding of the polyhedral combinatorics of the BMEP and may inspire the development of new and more effective exact solution algorithms based on implicit enumeration.

■ WB-16
Wednesday, 10:30-12:00 - Theatre A

Vehicle Routing II

Stream: Combinatorial Optimization II
Invited session
Chair: *Irene Loiseau*
Chair: *Anke Stieber*

1 - A Specialized Extension of the Median Tour Problem
Giovanni Campuzano, Carlos Obreque, German Paredes-Belmar, Pablo A. Miranda

In this work we present an extension of the Median Tour Problem and Generalized Traveling Salesman Problem (GTSP). The aim of this problem is to find a tour that visits all the clusters only once, and within each cluster visits a single node or at least one node. The remaining nodes within the same cluster are assigned to the tour. A bi-objective function is minimized jointly: the cost of the tour and the cost of accessibility to this tour. The cost of the tour is the sum of the costs of the arcs in the tour and the cost of accessibility is the sum of all the distances from the tour to all assigned nodes to the tour. Two extreme solutions are determined: if the cost of the tour is zero, then the solution that minimizes the allocation cost is the tour that visits the 1-median node within each cluster and if the allocation cost is zero, then the solution minimizes the cost of the tour. We present an integer programming model to solve the problem. In addition, we find the efficient frontier using a combination of the NISE algorithm and the constraints method. The models are programmed in C ++ language and solved by Cplex 12.8.0.

2 - A cost-efficiency heuristic for arc routing problems
Fábio Usberti, Rafael Kendy Arakaki

Given demands spread among the streets of a vicinity which must be attended for by multiple vehicles with limited capacities, what is the minimum total distance the vehicles must traverse to attend all the demands? This question is addressed by the capacitated arc routing problem (CARP), proposed by Golden and Wong (1981), with multiple repercussions in areas such as transportation, supply chain, meter reading, garbage collection, disaster relief. Path-scanning heuristics have been among the most successful constructive heuristics for the CARP. The path-scanning heuristic with ellipse rule, due to Santos et al. (2012), was shown to be effective in obtaining high quality solutions in short computational times. Building upon the ideas of Santos et al., this work presents a path-scanning with efficiency rule that uses information of the current vehicle (location, traversed distance and serviced demand) to decide the most promising edges to service next. Moreover, when the vehicle residual capacity reaches a certain threshold, the efficiency rule is triggered restricting the vehicle to service only edges that are classified as cost-efficient. Computational experiments were conducted to assess the performance of our methodology facing a benchmark of instances ranging from small to large networks (up to 375 edges). The results have shown that our approach consistently outperformed state-of-the-art path-scanning heuristics from literature while also being more parameter robust.

3 - Handling infeasible instances for the multiple traveling salesmen problem with moving targets.
Anke Stieber, Armin Fügenschuh

The multiple traveling salesmen problem with moving targets generalizes the classical traveling salesman problem. It considers more than one salesman and the targets (cities or objects) are not fixed, they are moving over time. Furthermore, each target is assigned a visibility time window. The goal is to find routes for the salesmen so that each target is intercepted exactly once within its visibility window and the sum of all traveled distances of all salesmen is minimal. Applications can be found in the defense sector and logistics.

Since the multiple traveling salesmen problem with moving targets is a problem with time, different modeling approaches to incorporate the time are considered. On one hand discrete time steps are used and on the other hand continuous time variables model the interception of salesmen and targets. Moreover, the time aspect can be included at different levels of the models. The different modeling approaches are compared regarding their runtime on randomly generated instances.

In the case of infeasible instances the limited amount of salesmen is not able to intercept all targets within their visibility time windows. Then, the goal is to catch as much targets as possible, traveling the shortest aggregated distances. We present appropriate adaptions to the models to cope with infeasible instances. Technically, this problem has to be solved online, but it can be realized by an offline optimization with a moving horizon approach.

■ WB-17

Wednesday, 10:30-12:00 - A005

Multi objective decision making in water management problems

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: *Rossana Riccardi*

1 - Multi-Criteria Decision Making for the Selection of Technologies: Resource Recovery from Wastewater
Seda Sucu, *Djamila Ouelhadj*

The population growth, significant boost in urbanisation, and reflection of consumption habits based on change in living standards have an important role in the projected water stress. This situation encourages the researchers in the field to investigate the technologies to reclaim the wasterwater and the shift from the conventional wastewater treatment technologies to novel resource recovery technologies. The selection of technologies for wastewater treatment has a great impact on the society, environment and the implementation cost of these technologies. NEREUS Project aims to develop a Decision Support Tool (DST) to assist the decision makers (policy makers, water authorities, process engineers) in the implementation of the wastewater recovery technologies considering the economic, social, environmental and technical impacts. In this presentation, we present the DST conceptual framework, the multi criteria decision making optimisation model, and the Life Cycle Analysis for wastewater recovery considering the economic, social, environmental and technical dimensions.

2 - A multiobjective bilevel optimization model for water system management
Herminia I. Calvete, *Carmen Galé*, *Pedro Mateo*

Distributing water has become one of the most important issues due to the growth of its uses and needs. In general, water resources are scarce to meet the whole needs of water demand sectors which, besides, can pursue different and even conflicting objectives. In the literature, the long-established modeling approach assumes a centralized planning. However, classical single level optimization cannot address the problems which arise in complex non-cooperative hierarchical water systems. These systems are characterized by the existence of two levels of decision making, which have different goals, often in conflict. Moreover, each decision maker only controls some of the decisions to be made. In this work we present and solve a bilevel optimization model to determine how to allocate the available water in a decentralized water resources system, taking into account the hierarchical structure of the decision process. On the one hand, a central authority aims to distribute water in accordance with environmental aspects and fairness in demand satisfaction. On the other hand, managers at demand points decide on the different uses of the allocated water based on maximizing the net economic return.

3 - Estimation of hydropower potential for analysis of the installation of Small Hidropower Plants, in the Paraíba do Sul river, in the South Fluminense region
Arthur Martins Seoane Monção, *Matheus Barbosa Cardozo*, *Eliane Christo*, *Kelly Costa*, *Leandro Monteiro*, *Luiza dos Santos*, *Glaudiane Almeida*, *Cecilia Toledo Hernandez*, *Christian Vargas*

The debate over the research and use of energy sources diversification, aimed to renewable sources, is justified as the effects of unrestrained use of unrenewable sources are been felt. The main advantages the Small Hydropower Plant (SHPs) have over the Larger Hydropower Plant are their reduced environment impact, ease installation and lower costs, both in installation and maintenance. The objective of this study is to analyze the hydropower potential (HP) of one of the largest hydrographic basins in Brazil, Paraíba do Sul river, besides evaluating the possible installation of SHPs in the South Fluminense (SF) region. At the first stage of the project, historical series of flow and quota were analyzed, based on the data provided by the National Water Agency of Brazil. Aftwerwards, with the help of the QGIS 2.14 software, the SF region planialtimetry was performed. The course of the river was divided into 28 points for analysis, with an average of 5 km distance. With the data provided and using the equation of hydraulic energy, it was possible to obtain the HP between the adjacent points. From the 28 points, 16 presented consistent HP for the SPHs. The regions between the cities of Vargem Alegre and Barra Mansa and between Itatiaia and Resende were those which presented the highest results, ranging an average of 23MW, nearly 10MW more than the other regions included in the study. With this analysis, the HP of the SF region is contemplated, mainly between these cities.

4 - Water investment planning: an optimization model for assessing efficiency and sustainability
Rossana Riccardi, *Elisabetta Allevi*

Providing secure and reliable water supply service to major urban areas has become a considerable challenge in recent years on a global basis. Water shortages throughout the world have shaped the development of demand management and supply enhancement options to improve water supply reliability. Climate change adds another layer of deep uncertainty to forecast surface water availability. The society is facing a trade-off between cost of a water supply-demand strategy and water shortage risks in the long run. For urban pumping reservoir, there are considerable additional costs for purification to make the water safe and healthy for human consumption. An important cost to be considered is the considerable increase in water purification costs. This work presents an investment decision-making tool to identify a portfolio of sustainable efficiency improvements, flood control investments that the market regulator authority can implement pursuing the objective of minimizing water shortage severity while achieving a target level of reliable service. The optimization model aims at minimizing the costs of water supply-demand portfolios over the entire planning horizon: capital and construction costs, operation and maintenance costs, social costs, and environmental costs. A set of constraints needs to be met while optimizing the objective. These constraints model the water balance, operation, and capacity of physical supply systems as well as compliance with environmental regulation

■ WB-18

Wednesday, 10:30-12:00 - C112

New Applications and Perspectives

Stream: Data Mining and Statistics
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Ivan Reyer*
Chair: *Andreas Alpers*

1 - Predictive modeling to gain insights in voter profiles in Flanders
Stiene Praet, Peter Van Aelst, David Martens

Voting behavior and party preference are well-studied by political scientists who try to explain how and why decisions are made by the electorate. Traditionally, scholars relied on structured data, such as election outcomes and surveys, to understand people's vote. Today, thanks to the Internet and social media, an unseen amount and granularity of data is available. In this study we demonstrate how political insights can be gained from high-dimensional and sparse data, by analyzing Facebook 'like' and survey data of more than 6.500 Flemish participants. Using logistic regression models we show that it is possible to predict political leaning and party preference based on Facebook likes, even when excluding the political Facebook likes. Secondly, we compare several metrics that measure the association between Facebook likes and political affiliation to describe voter profiles in terms of common interests. For example, left voters often like environmental organizations and alternative rock music, whereas right voters like Flemish nationalistic content and techno music. The contributions of this study are three-fold: (1) this is the first study analyzing Facebook page likes to predict political leaning (left-right) and party preference in a European multi-party context, (2) we develop a novel methodology to analyze voter profiles based on Facebook likes and (3) we provide insights into voter profiles that offer opportunities for political theory building.

2 - Analysing Incomplete Data using NCARBS and Retaining the Missing Values in the Analysis: The Case of Sensitive Data
Malcolm Beynon, Rhys Andrews, Rachel Ashworth

The N-state Classification and Ranking Belief Simplex (NCaRBS) technique is a non-parametric technique for data analysis, with its methodological basis is Dempster-Shafer Theory (belief functions), and offers a general framework for reasoning with uncertainty. An important feature of the NCaRBS technique is its ability to analysis incomplete data without the need to manage the missing values present. In the case of analysing sensitive data, whether such a variable is representative or not, may mean it is included or not in an analysis, here NCaRBS can allow this at the individual variable value level (not a whole variable must be discarded), since it can allow missing values (unrepresentative values). The study considers a workforce exclusion survey of UK public sector organisations, with a novel hybrid exclusion outcome measure made up of a triplet of values, non-inclusion, discrimination and bullied. Condition variables are considered, including a measure of disability within the employees of an organisation to gauge against the outcome measures. The results, through a series of NCARBS analyses, show the inclusion of some 'representative' sensitive variable values is better than not including the variable at all or including all the variable values. Emphasis throughout the study is on the graphical elucidation of results. The analysis will show how a missing value can be representing evidence, actually ignorance, in a n-state classification problem.

3 - Compressed domain video analysis and retrieval based on continuous image morphology
Ivan Reyer, Ksenia Aminova

An approach to content-based video retrieval and analysis is considered. A "continuous" representation of a segmented raster frame consisting of a set of nonoverlapping polygonal figures is constructed. Each polygon from the set approximates a homogeneous raster region within the frame, with polygons of two neighbour regions having common fragments of boundary. To obtain the set of polygons a modified algorithm for approximation of a binary image with polygons of minimal perimeter is used. The model also includes marked skeletons of polygons describing skeletal representations' changes at increase of the approximation accuracy value. Thus, a polygonal figure generates a family of variously detailed boundary-skeleton shape models. Constructed frame models are compared by shape and color of polygons. To estimate the shape similarity, integral morphological features are compared. The applications of the presented approach to retrieval and analysis of video sequences in compressed domain with use of partially decompressed I-frames and motion compensation information are described.

■ WB-19
Wednesday, 10:30-12:00 - C115

Emerging Applications in Management Science: Machine Learning

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: *Chansoo Kim*
Chair: *Stefano Marmani*

1 - How People Herd in Financial Markets and Inequalities Emerges: Stochastic Deep Learning Analysis
Chansoo Kim, Haneol Cho, Kyung O Baek

We define behavioral parameters to describe interactions among participants based on a Stochastic Agent-based Model (ABM), which simulates price dynamics of financial markets. The model includes level of each participant's influence, gullibility, activism and propensity. We fit our model to the real estates market of Seoul in Korea and KOSPI (Korea Composite Stock Price Index) 200 market. Stochastic deep learning controls the parameters, which are sampled from graphical distributions, to produce better result. And it mainly deals herding behaviors of market participants. Both markets manifest heavy-tailed distribution: price inequalities in the real estate market and agents' earning rates inequalities in the KOSPI-200. We show degree of inequality is explained by the market herding revealed by parameters from the deep-learning fits.

2 - A Machine Learning Framework for Neighbourhood Safety Impact Prediction
Christine Cao, Laleh Behjat

The advent of data mining and machine learning is bringing about a new revolution in data analytics in many different fields. One such emerging application is using the massive amount of governance data to achieve a data-driven design in urban neighbourhood safety. A supervised machine learning-based model is developed to mine available data in order to determine the impact of neighbourhood features on the safety of urban neighbourhood design.

Governments often provide open data from various sources, including spatial data, demographic data, and resident movement. Combined with images from Google Street View, these data are used in a proposed feature extraction and impact prediction algorithm, based on supervised machine learning. In this model, features (physical neighbourhood features) are first extracted from available data. Then, all extracted features are used to make predictions on their impact on neighbourhood safety. The features that are most impactful on the neighbourhood safety are identified and used to recommend changes that improves the neighbourhood.

This method of data analytics using machine learning has transferrable applications, and can be applied to understand other issues, such as integrated circuit design and traffic planning. Also, this model can improve urban neighbourhood safety, increasing both the quality of life of citizens and government efficiency in resource management.

3 - Quantitative analysis of qualitative data delivered on Bloomberg news: a text mining rank size analysis
Thamila Madji, Stefano Marmani, Valerio Ficcadenti, Babar Syed, Gurjeet Dhesi

This work presents a text mining context and its use for a deep analysis of the messages delivered by Bloomberg news. Specifically, we deal with an expert systems-based exploration of the rhetoric dynamics of a large collection of Bloomberg news, and in this research tentatively applied to Latin America . In particular, economic, financial and political news are viewed as complex expert systems whose structures can be effectively analyzed through rank-size laws. The methodological contribution of the research is twofold. First, we develop a text mining-based procedure for the construction of the dataset. Second, we explore the implicit structure of the discourse data by implementing a rank-size procedure, the words of the news ranked in terms of their frequencies. The scientific significance of the proposed combination of text-mining and rank-size approaches can be found in its flexibility and generality, which let it be reproducible to a wide set of expert systems and text mining contexts. The usefulness of the proposed method and of the Bloomberg news analysis is demonstrated by the findings themselves. Indeed, in terms of impact, it is worth noting how the Bloomberg news affect the decision taking of the single subjects generating mass effects on the market.

■ WB-20

Wednesday, 10:30-12:00 - C006

Emerging Research on Labor Markets, New Technologies and Competences

Stream: Emerging Research on Education, Labor Markets and Transversal Competences
Invited session
Chair: *Magdalena Graczyk-Kucharska*
Chair: *Małgorzata Spychała*
Chair: *Gerhard-Wilhelm Weber*

1 - Spatio-temporal approach: Changes in German Economic Structure
Simona Mackova

Nearly thirty years has passed from the German reunion. Since the two parts were developing separately for ages, former western Germany entered the new republic as economically much stronger member. After this quite long period, this gap definitely narrowed or maybe even disappeared. Some theories state that German economy is transforming into the more traditional model of north-south divide, where southern part is the drive of the country with most of the industry and business in this case. This contribution applies spatio-temporal approaches to analyse economical gaps, their significance and development in time. One of the irreplaceable tools of spatial econometrics are cartograms using NUTS-3 regional division that capture well the situation graphically. As a measurement of economic prosperity are used variables as gross domestic product, employment and industrial diversity. Also variables as life birth by age group of the mothers are not neglected. Models based on spatial analysis involving panel data are constructed to prove our assumption of changes of economic structure of Germany.

2 - Early segmentation of students according to their academic performance: A predictive modelling approach
Vera Miguéis

The early classification of university students according to their potential academic performance can be a useful strategy to mitigate failure, to promote the achievement of better results and to better manage resources in higher education institutions. This paper proposes a two-stage model, supported by data mining techniques, that uses the information available at the end of the first year of students' academic career (path) to predict their overall academic performance. Unlike most literature on educational data mining, academic success is inferred from both the average grade achieved and the time taken to conclude the degree. Furthermore, this study proposes to segment students based on the dichotomy between the evidence of failure or high performance at the beginning of the degree program, and the students' performance levels predicted by the model. A data set of 2459 students, spanning the years from 2003 to 2015, from a European Engineering School of a public research University, is used to validate the proposed methodology. The empirical results demonstrate the ability of the proposed model to predict the students' performance level with an accuracy above 95%, in an early stage of the students' academic path. It is found that random forests are superior to the other classification techniques that were considered. Together with the prediction model, the suggested segmentation framework represents a useful tool to delineate the optimum strategies to apply.

3 - Data mining methods used for designing the acceleration model of team collaboration competence development
Małgorzata Spychała, Magdalena Graczyk-Kucharska, Robert Olszewski, Marek Goliński

Theory of knowledge-based economy is becoming strong movement described by analysis of the real socio-economic situation. Social capital and undertaken by the society competences ensure human resources. The consequence of it is foster sustainable economic development. Among competences needed by entrepreneurships for a wide range of professions are among others: team collaboration, creativity, communicativeness or entrepreneurship. The main objective of this paper is to develop the model, that indicates different variables, which may influence acceleration of team collaboration competence developed among students. Collected research data were analyzed with the used of Multiple Linear Regression Model, Nonparametric Regression Methods, e.g., Multivariate Adaptive Regression Splines, also Data Mining Techniques - Decision Trees and Artificial Neutral Network. Presented models allow to explain almost 90% of variability of the phenomenon described by collected data. The studies allow for selecting of key explanatory variables describing acceleration of transversal competence occurrence, also help in comparison of efficiency of particular methods. The results may be used in decision making process for choosing the best teaching methods of the students, thus helping them in acceleration of team collaboration competence development needed almost at each workstation in different professions.

■ WB-21

Wednesday, 10:30-12:00 - F101

Selected Topics

Stream: Algorithms on Graphs
Invited session
Chair: *Stephan Westphal*

1 - Mechanisms for Scheduling Jobs with Unknown Processing Times on Unrelated Machines
Felix Merz, Christoph Schwindt, Stephan Westphal, Jürgen Zimmermann

In a dismantling factory, various recycling and remanufacturing jobs can be carried out by human-machine teams. The jobs occurring in this scenario are complex and diverse, leading to a different suitability of workers for each job based on their respective skill profile and work experience. The individual processing times are therefore dependent on the worker and the job and can be best estimated by the workers themselves. The lack of knowledge about processing times makes the central planning of the job allocation difficult. However, the allocation of jobs through mechanisms based on workers' estimates is promising.

In this paper, we consider a basic scenario with dismantling jobs being processed by workers on unrelated machines. In order to avoid that the most qualified workers take over the majority of the jobs while some workers are idle, restrictions on their maximum workload are needed.

In this context, the problem of assigning jobs to workers can be modelled as a scheduling problem with jobs on unrelated machines with unknown processing times and maximum machine load.

We discuss several variants of the problem, present mechanisms, the corresponding equilibrium solutions and evaluate their quality.

2 - A Branch & Bound Algorithm to Determine Optimal Bivariate Splits for Oblique Decision Tree Induction
Ferdinand Bollwein, Stephan Westphal

Univariate decision tree induction methods for multiclass classification problems such as CART, C4.5 and ID3 continue to be very popular in the context of machine learning due to their major benefit of being easy to interpret. However, as these trees only consider a single attribute per node, the resulting trees often get quite large which lowers their explanatory value. Oblique decision tree building algorithms, which divide the feature space by multidimensional hyperplanes, often produce much smaller trees but the individual splits are hard to interpret. Moreover, the effort of finding optimal oblique splits is very high such that heuristics have to be applied to determine local optimal solutions. In this work, we introduce an effective branch and bound procedure to determine optimal bivariate oblique splits for concave impurity measures. Decision trees based on these bivariate splits remain fairly interpretable due to the restriction to two attributes per split. The resulting trees are considerably smaller and more accurate than their univariate counterparts due to their ability of adapting better to the underlying data and capturing interactions of attribute pairs. Moreover, our evaluation shows that our algorithm performs comparable to tree building algorithms based on heuristically obtained multivariate oblique splits, despite the fact that we are focusing on two attributes only.

3 - An IP based heuristic algorithm for the Pallet Loading Problem with malleable box sizes
Martin Dahmen, Stephan Westphal

The Pallet Loading Problem (PLP) describes the task of maximizing the number of rectangular boxes that fit onto a rectangular pallet without overlapping. The most common and widely studied classifications of the problem are the manufacturer's and the distributor's version, which are different only insofar as they consider identical boxes only or allow heterogenous box sizes. Motivated by the real case application of placing packaging material into shipping boxes, we introduce a new version of the Pallet Loading Problem where homogenous boxes with malleable shapes have to be packed within a rectangular pallet. Therefore, all boxes are given a common degree of elasticity and under the restriction that the volumes of the individual boxes have to remain unchanged, boxes of different shapes may appear in an optimal solution. We present an IP based heuristic approach to identify optimal packing patterns and to solve the pallet loading problem with malleable box sizes. This approach can be carried over to the real case scenario with 3 dimensions, providing an approximation algorithm with practical impact.

■ WB-22
Wednesday, 10:30-12:00 - F102

Incentives and Pricing in Sustainable Supply Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Grigory Pishchulov

1 - Social equity in supplier-buyer relationships in smallholder agri-food supply chains
Nayeli Hernandez-Martinez, Nevin Mutlu, Jan Fransoo

We study supplier-buyer relationships in smallholder agri-food supply chains with equity concerns and under stakeholder engagement. Motivated by the case of socially responsible Mexican company Fractal Café, we develop a game theoretic model to study the impact of these socially responsible practices in investment and pricing decisions. We model this as a Stackelberg game in two stages. We provide closed form expressions for the optimal wholesale and retail prices, and characterize the structure of the optimal investment decisions. We numerically compare the outcomes of a standard profit maximizing model to our proposed model with socially responsible practices. We also study the effect of the model parameters and the price of ignoring the equity concerns. We show that equity concerns drive a redistribution of the profit towards an equitable outcome, but they do not have the same effect on the investment decisions. Additionally, we show that equity concerns can potentially reverse the advantage of the game leader and that, under the right circumstances, the introduction of socially responsible practices can increase the total supply chain profit.

2 - Engaging in supplier compliance through audits and supplier capability development
Grigory Pishchulov, Fahian Huq

Compliance of suppliers with environmental and safety regulations has become of a concern for the buying firms, as the lack of supplier compliance puts the buyer's brand reputation at risk. By auditing the suppliers, buying firms intend to detect and penalize non-compliance. Existing research offers game-theoretic analyses of the level of effort to be exerted by suppliers towards ensuring compliance, and by buyers — towards auditing. Still, this body of work disregards the opportunity for the buyers to engage in supplier capability development, in addition to conducting supplier audits. We extend the existing modeling framework in this respect by including supplier development effort in the model and compare game-theoretic solutions in a single-supplier-two-buyer setting with the ones provided by existing models.

■ WB-23
Wednesday, 10:30-12:00 - F103

Methods for Financial Modelling

Stream: New Challenges in Investment Strategies, Risk and Financial Modelling
Invited session
Chair: Roy Cerqueti

1 - Communities in complex networks and applications in finance
Roy Cerqueti

This talk elaborates on the community structures of complex networks. We present the remarkable cases of different levels of communities and the existence of not explicit links of indirect and social type. At this aim, extensions of the clustering coefficients of the nodes are introduced and discussed. The usefulness of the assessment of the communities in a network for describing its riskiness is explored with peculiar attention. Paradigmatic examples illustrate the theoretical results and validate the framework, assisting also the reader in having an intuitive view of the presented concepts and how they can be applied in the financial context.

2 - Structural Pricing of XVA Metrics with Stochastic Recovery Rates
Rosella Castellano

The global financial crisis revealed that no economic entity can be considered default-free. Both banks and corporations have to deal with bilateral Counterparty Credit Risk in their Over the Counter derivatives trades. This implies the need to price these risks, namely the Credit Valuation Adjustment and its counterpart, the Debt Valuation Adjustment. Differently from the commonly used reduced-form approach, in this paper we address a structural approach in which bankruptcy is modelled as the first-passage time of firm equity value from a predetermined lower barrier. Moreover, the numerical computation of the valuation adjustments for bilateral Counterparty Credit Risk in the context of energy commodities Over the Counter derivatives contracts has been performed. Furthermore, state-dependent stochastic recovery rates were introduced in the model in order to analyze the impact on Counterparty Credit Risk.

3 - Impact of president speech on US dollar value
Rouhollah Ebrahimabadi, Gurjeet Dhesi

The analysis is preformed by extending the GARCH to include a dummy variable of 1 when the speech is being delivered. For our sample speeches the dummy variable is significant and the goodness of fit statistics is improved further it is observed that the volatility of the exchange rate substantially altered during speech time.

4 - The intraday order dynamics: A multivariate Poisson autoregression analysis
Ana Escribano, Antonio Díaz, Francisco Jareño, Mario Maggi

This paper analyzes the intraday flow of orders in a stock exchange. A Multivariate Autoregressive Conditional Poisson model, with intraday seasonal effect is propsed and applied to the study of high frequency data of the Banking and Insurance companies listed in the Italian Stock Exchange. The estimation results allow to discuss the roles of the various company, detecting the leading ones and some cross effects in the flows of orders.

■ WB-24

Wednesday, 10:30-12:00 - F103A

Game Theory & Supply Chain Coordination

Stream: Supply Chain Management
Invited session
Chair: Michael Vidalis

1 - Optimal vendor managed inventory for a three level supply chain with lost demand and Coxian-2 lead times.
Michael Vidalis, George Varlas, Stelios Koukoumialos, Alexandros Diamantidis

Supply chain management determines flows between supply chain stages in order to maximize the total supply chain profit. One key factor is inventory management. Among the proposed philosophies is the vendor managed inventory (VMI) practice: the supplier is fully responsible for managing the retailer's inventory. We investigate a three-echelon serial supply chain with stochastic external demand and Coxian-2 replenishment times under the VMI philosophy. The system is modeled as a continuous time - discreet space Markov process. We develop an algorithm to construct the generator matrix for any combination of decision variables, based on the recognition of repetitive blocks of states or sub-matrices. We use stationary probabilities to compute key performance measures such as satisfaction of demand, average inventories, and resources utilization. The algorithm can be used to explore the complex dynamics of VMI systems, evaluate different scenarios and obtain managerial insights about optimal working parameters.

2 - Lead time quotations in unobservable make-to-order systems with strategic customers: risk aversion, load control and profit maximization
Myron Benioudakis, George Ioannou, Apostolos Burnetas

We consider mathematical models for pricing, lead time quotations and delay compensations in production and service systems with strategic customers. Methodologically it lies on the interface between Game theory and Queuing theory. The application framework is a MTO production system with lead-time quotations and strategic customers with risk aversion to delay. Specifically, we consider a MTO system where customers arrive according to a Poisson process, and the production/service times are i.i.d. exponential random variables. This gives rise to an M/M/1 queuing model. Customers make individual decision to join the system or balk. Customers know the potential arrival rate and the economic parameters are common to all. The individual decisions of arriving customers result in a symmetric join/balk game, for which a Nash equilibrium can be identified using game theory methodology. We consider this problem under two approaches. The first one is the case where the provider maximizes his own profits. We prove analytically properties of the optimal price and compensation policy, under a general concave utility function. Under the second approach, the provider wants to control the entrance rate by setting appropriate fees and a compensation scheme. This is a common situation in practice. Under this approach, we identify intervals of achievable entrance rates and construct price-lead time and price-compensation curves that guarantee them. Finally, we present numerical results.

3 - Competitive New Product Sales with Externalities
Yufei Huang, Zhengfeng Li

When deciding whether to adopt a new product, consumers often have uncertainty regarding the quality and functionality of the new product. In new product sales competition, firms need to devise not only the prices but also how to convince consumers by reducing their uncertainty. In this paper, we use a game-theoretic model to study the firm's optimal strategy to compete in new product sales, by considering positive externalities among consumers. Our equilibrium analysis reveals that investing to reduce consumers' uncertainty does not always benefit the firm itself, as educating consumers can also help its competitor in new product sales.

4 - Consistent Allocation of Emission Responsibility in Energy Supply Chains
Daniel Granot, Sanjith Gopalakrishnan, Frieda Granot

Canada's federal government, since 2016, has pledged to factor in upstream emissions during the environmental impact assessment of fossil fuel energy projects. The upstream emissions attributable to a proposed project could be compared against a rejection threshold - a maximum permissible level of emissions, or the firm could be mandated to offset the attributed emissions. We adopt a cooperative game-theoretic model, and propose the nucleolus to attribute upstream emission responsibilities in energy supply chains. The nucleolus allocation avoids the distortionary effects of double counting and exhibits a certain consistency property that is especially important in a regulatory context wherein energy supply chains span multiple legal jurisdictions. Further, among other results, (i) we develop an O(n2) algorithm to compute the nucleolus, where n is the number of firms in the supply chain, (ii) we prove that the nucleolus is the unique strong-Nash equilibrium in a non-cooperative game associated with the emission allocation problem, (iii) we provide a non-cooperative implementation framework for the nucleolus allocation, in terms of two easily stated and verifiable policies, (iv) we prove that the nucleolus allocation is piece-wise linear and increasing in the direct emission of a firm, (v) and we extend our base model by introducing carbon pricing and investigate the power of the nucleolus allocation to incentivize firms to adopt abating technologies.

■ WB-25

Wednesday, 10:30-12:00 - F104

Uncertainty in Production and Service Management

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: Young H. Chun

1 - Scheduling and acceleration of clinical trials for drug development under uncertainty
Xin Fei, Juergen Branke, Nalan Gulpinar

Drug development is a process of testing efficacy of experimental drugs in a series of clinical trials, entrenched with a high uncertainty, that an experimental drug will eventually get market approval. The profitability of drug development relies on an effective strategic decision-making that comprises clinical trial scheduling and resource allocation across multiple drug projects. In this study, the clinical trial scheduling and resource allocation problem in drug development under uncertainty is formulated as a discrete-time finite Markov decision process and an adaptive rollout algorithm is introduced for the curse of dimensionality arisen in the stochastic dynamic program model. The proposed algorithm includes two computationally effective innovations. First, a base policy is used to obtain optimistic estimates of future outcomes after taking a particular action at each state of a decision tree. Second, an adaptive sampling approach is proposed to balance exploration and exploitation of the rollout algorithm, which exploits a variance reduction technique of common random numbers as well as the empirical Bernstein inequality in a statistical racing procedure. In addition, we present an augmented adaptive sampling approach that utilises a heuristic-based grouping rule to enhance the simulation efficiency. The numerical results show that the proposed methods provide competitive results within a reasonable computational time.

2 - Bi-objective DDMRP buffer location problem
Hamid Allaoui, Abdelhalim Achergui, Tiente Hsu

Demand Driven Material Requirement Planning (DDMRP) is a recent supply chain planning and execution method. It is considered as a solution for the unstable and unreliable forecasted demand. The first component of this method is determining the buffer location in the manufacturing facilities and the supply chain network, on both the strategic level and the tactical level. Hence the importance of the buffer location optimization problem is highlighted. The research work focuses on the strategic level of where to put the buffers through the supply chain network. The current buffer location technique is based on satisfying the positioning factors. To determine the optimal decisions, we use a multi-objective method minimizing both the lead-time of products and the inventory cost across the bill of materials, while still meeting the positioning factors constraints. The multitude of products in a company can make the subject more complicated, which calls for several simulations of potential buffer locations. This study gives better answers regarding the effectiveness of buffer location in a supply chain.

3 - Improving healthcare inventory management with service level differentiation
Luis Girão, Gonçalo Figueira, Mário Amorim Lopes

Healthcare facilities have a broad range of items to manage and stock-outs might have serious implications for the patients' quality of care and the operational performance of the institutions. Inventory management is one of the most important activities in the pharmaceutical department, where several items face intermittent consumption patterns and stock-outs trigger new request processes, hence the alpha service level is typically chosen. The intermittent patterns are challenging in an inventory control perspective as they require specific forecasting methods, already used in the field of spare parts management. Moreover, to calculate the inventory policy parameters the normal assumption does not work well, so one needs to fit lead time demand to other distributions. The literature has studied this issue by comparing different distributions and proposing a new goodness of fit test. However, the existing methodologies do not achieve the expected service levels. We present a new approach which differentiates the target service level based on the standard deviation of the lead time demand. At every period the grouping step is made, assigning different service levels for each group. The new approach was simulated using a well-known dataset from the literature of spare parts and a new dataset from the healthcare sector with more than 5000 items. The results show that the new approach is more efficient, achieving the same service level with 30% less average inventory.

4 - Designing a Repetitive Inspection Plan Based on the Run Length of Test Results
Young H. Chun

Consider a typical inspection process, in which a batch of components consists of "defective" and "non-defective" items. Each item is tested at the inspection point, and the test result is either "positive" or "negative". Based on the test result, the acceptance-rejection decision is made, and only the accepted items are shipped to customers. However, inspection or misclassification errors are inevitable in any inspection and testing processes. That is why a batch of critical components, such as computer chips, is often tested repeatedly to improve the outgoing quality. Various repetitive inspection plans have been proposed to minimize the expected total cost of inspection and misclassifications. We propose a new type of repetitive inspection plan that is based on the run-length of positive and negative test results. In a numerical analysis, we show that the new inspection plan outperforms previous ones in terms of the expected total cost as well as the average outgoing quality. Most inspection models are based on three parameters: the fraction defective of incoming items and the type I and II errors of a testing device. These parameters are often assumed to be known in advance, but we propose the use of a Bayesian method to estimate the point and interval estimates of the unknown parameters. We show that computational difficulties with prior distributions of the three parameters can be easily overcome with an appropriate Markov chain Monte Carlo method.

■ WB-26

Wednesday, 10:30-12:00 - F106

EthOR award ceremony, Group meeting & Honouring Dr. Antoinette Muntjewerff

Stream: OR and Ethics
Contributed session
Chair: *Pierre Kunsch*
Chair: *Cathal MacSwiney Brugha*
Chair: *Ulrike Reisach*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Elise del Rosario*

1 - EthOR award ceremony - EWG meeting Ethics and OR
Pierre Kunsch

This is a dummy abstract to announce this session. No presentation in relation with the EthOR award will be made

The session will start with the EthOR award ceremony nominating the winner and two finalists. Certificates will be handed over.

The award ceremony will be followed by the meeting of the working group Ethics and OR

■ WB-27

Wednesday, 10:30-12:00 - F107

Optimization in Social Networks II

Stream: Network Analytics and Optimization
Invited session
Chair: *Ignacio Inostroza-Quezada*

1 - The Forward Linear Threshold Rank
Maria J. Blesa, Maria Serna, Eline van Hove

Centrality and influence spread are two of the most studied concepts in social network analysis. Centrality aims at finding out how important actors within the network are. Traditional centrality measures are related to the topology of the network. The spread of influence models the ways in which actors influence each other through their interactions. The Linear Threshold model (LTM) is one of the most general models for influence spread. Based on it, the Linear Threshold Rank (LTR) was recently proposed in [Knowledge-Based Systems 140; 2018] as a new centrality measure, where the centrality of a node is the number of nodes that can be influenced (under the LTM) when the node and its direct neighbors are the initiators.

We propose the Forward Linear Threshold Rank (FLTR) and variations, which conform a new branch of centrality measures that aim at overcoming some lacks of the LTR. These new measures consider that the influence relation between two nodes may not be symmetrical, that the spreading time matters, and that the set initiating the influence may consider not only direct neighbors, but neighbors up to a certain distance. These new measures come out to be clearly different when compared to the existing ones on real social networks of different nature. Moreover, they are able to quantify the influential importance of network actors in a more realistic and general way.

Partially supported by TIN2017-86727-C2-1-R (GRAMM).

2 - New Centrality Indices, their Matrix-Vector Representation and their Applications

Fuad Aleskerov

We present matrix-vector representation of several new centrality indices for networks. Some of these indices represent solution concepts from social choice theory, others present the concepts of power based on solution concepts in cooperative game theory. The latter indices take into account the parameters of the nodes in networks, a possibility of group influence from the subset of nodes to single nodes, and intensity of short and long range interactions among the nodes. Several applications to real networks are studied - conflicts, migration, student mobility, international trade, remittance flows, foreign claims, international terrorism, etc.

3 - Solving Very Large Scale Covering Location Problems using Benders and Submodular Cuts

Fabio Furini, Ivana Ljubic, Jean-Francois Cordeau

Covering problems constitute an important family of facility location problems with widespread applications. These problems embed a notion of proximity (or coverage radius) that specifies whether a given demand point can be served or “covered” by a potential facility location. Proximity is often defined in terms of distance or travel time between points. A demand point is then said to be covered by a facility if it lies within the coverage radius of this facility. Location problems with covering objectives or constraints are commonplace in the service sector (schools, hospitals, libraries, restaurants, retail outlets, bank branches) as well as in the location of emergency facilities or vehicles (fire stations, ambulances, oil spill equipments). They also find applications in the location of access points for the wireless communication in the smart grid deployments. Many of these applications involve a relatively small number of potential facility locations while the number of demand points can run in the thousands or even millions. Such very large scale problem instances remain out of reach for modern MIP solvers.

4 - Experience Effects in a Consumer-level Diffusion Model for a Durable New Product among Heterogeneous Consumers in a Social Network

Ignacio Inostroza-Quezada

Before launching a new product, a manager should attempt to i) set its optimal unit-selling price and ii) identify the most influential consumers to ignite the diffusion process. The talk presents a Bayesian-learning diffusion model for a durable new product launched in a market of potential adopters who are connected in a social network with density smaller than one. In this model, potential adopters have heterogeneous perceptions about the new product’s quality and heterogeneous local structure of connections in the social network. Along the diffusion process, each potential adopter decides whether to adopt based on an individual utility function that can update with signals from prior adopters connected with him. These signals reflect the experiences of these prior adopters with the new product. I conduct simulations to study the relationship between the structure of connections among potential adopters and the optimal pricing strategy of the new product along the diffusion process. To measure structure of connections, I use: i) randomness of connections, based on Watts and Strogatz’s (1998) model, and ii) network density, i.e. the proportion of actual to potential connections. Both characteristics are of wide use in social network theory. To learn about the role of the strategic location of early adopters, I study this relationship when the new product is launched i) to all potential adopters and ii) only to potential adopters with the largest network centrality.

■ WB-28

Wednesday, 10:30-12:00 - G102

Management Accounting

Stream: Operational Research in Financial and Management Accounting
Invited session
Chair: Christian Fritze
Chair: *Marius Hölscher*

1 - Styling of facts in maintenance and repair of municipal infrastructure

Christian Fritze

With the latest legislative reform in German budget law, municipalities shall be stimulated to spend more money in maintenance and repair of local infrastructure. Therefor new rules give municipalities the opportunity to activate these expenses in order to allocate them over several years instead of just the one of taking the action. To do so, budget law requires that the maintenance and repair is so large that it comes to an extension of the asset’s economic lifetime. Thus municipalities need to consider this possibility when deciding whether to invest in maintenance and repair and in what amount. I present an approach for finding the optimal investment decision considering budget law’s requirement for balanced budget in each year.

2 - Identifying key performance indicators with neural networks

Marius Hölscher

Analysing the capability of artificial neural networks (ANN) to identify key performance indicators (KPI) and creating an accounting data driven decision-making tool is the basic idea of this research. In a controlling view, we want to specify the role of KPIs and the prediction of future KPIs in the context of decision-making. We choose a value-based management (VBM) approach and Monte-Carlo-Simulation KPI-identification improved by using ANN. Identifying future KPIs in a VBM view leads to an empowered capability of KPI-identification and enhances decision-making.

3 - Supporting a performance-oriented management accounting system by simulation

Lidia Malizia, Rina Mary Mazza

Performance measurement has become a legislative requirement in the Italian public sector. The objective is to lead to a transparent organization, while allocating scarce resources more carefully. As a result, management accounting systems must provide the underlying measures of performance to steer public organizations in the direction of performance-driven budget allocation. We report on our initial research efforts to support a performance-oriented accounting system in the management of research projects carried out within a public university with respect to a five-variable performance paradigm: time, costs, resources, quality and risk. To do so, we are conducting a simulation study to assess the performance delivered by the model under: alternative organizational models such as common or dedicated project management facilities; resource allocation policies with limited availability of skilled and shared personnel; conflict-free activity scheduling in the project management operations.

4 - Activity based cost modelling using discrete event simulation for evaluating new outpatient elective pathways
Gillian Anderson, Margaret Nugent, Lech Rymaszewski, Robert van der Meer

The traditional outpatient pathway requires modernisation as people referred to hospital routinely wait for months for a face-to-face (F2F) appointment. Appropriate management of their condition is delayed, causing anxiety and uncertainty. No clinical information is usually sought or provided until individuals are actually seen, despite the accessibility of electronic patient records, laboratory results and imaging. A trial of an additional process in the Orthopaedic Unit at Glasgow Royal Infirmary (402 patients) demonstrated that if clinical information is sent to selected individuals immediately after triage, with the opportunity to 'opt-in' for telephone discussion or a F2F review, only 48% contacted the department. Patient satisfaction with this system was high - 89% out of 150 who responded to a questionnaire. A generic discrete event simulation model was developed to compare the time driven activity based costing (TDABC) of the "triage/opt-in" model compared with a traditional process. The financial benefit of this redesign can now be estimated for any situation, as additional investment in the redesign results in the demand for F2F review being greatly reduced. The analysis can support this transformational redesign in any specialty, as a commonly-held belief is that such a system would be too expensive. Overall, patients are better informed, share in the decision-making and the resources freed-up can be re-invested in clinical care.

■ WB-29

Wednesday, 10:30-12:00 - C118

Emerging Models for Transportation with Crowdsourcing

Stream: Emerging Models for Transportation with Crowdsourcing
Invited session
Chair: *Katarzyna Gdowska*
Chair: *Kseniia Klimentova*
Chair: *João Pedro Pedroso*
Chair: *Ana Viana*

1 - Crowdsourced Logistics: The Pickup and Delivery Problem with Transshipments and Occasional Drivers
Stefan Voigt, Heinrich Kuhn

An application of the Sharing Economy is crowdshipping, where occasional drivers (ODs) share their time and excess capacity of their vehicle to ship parcels. We consider a setting, in which a carrier operates a fleet of vehicles with regular drivers (RDs) to ship parcels from pickup to delivery points. Additionally, the carrier uses a platform where ODs offer their willingness to fulfil pickup/delivery tasks. To better integrate the ODs the carrier operates transshipment points. At these transshipment points ODs or RDs can hand over or take on, respectively, their freight. The carrier has to decide which tasks are assigned to RDs, which to ODs, in which sequence the drivers attain to the customers and whether transshipment points are used. The carrier aims to minimize the overall costs, which arise from the distance travelled by RDs and the compensation paid to ODs.

The problem at hand is modelled as MIP and called Pickup and Delivery Problem with Transshipments and Occasional Drivers (PDPTOD). We develop a solution approach based on an Adaptive Large Neighbourhood Search in a Simulated Annealing framework, which solves practical-size problem instances within reasonable time. We conduct numerical experiments on well-known instances extended by ODs and transhipment points. We conclude that introducing transshipment points is an opportunity to reduce costs. However, the potential depends on the instance at hand and is sensitive to the assumed compensation scheme.

2 - Stochastic last-mile delivery with crowdshipping
Kseniia Klimentova, João Pedro Pedroso, Ana Viana

Sustainability concerns and the growth of e-commerce in recent years put pressure on companies to develop new business models to deal with last-mile delivery – the last stage of the supply chain, where a parcel is delivered to the final consumer. Most research done in this area concerns same-day delivery, performed by casual couriers (CC) and a professional fleet (PF) in the following way: if some packages remain not assigned to CCs, they must be delivered by the PF. A company's objective is to minimize the total delivery cost, i.e., the cost associated with delivery using the PF added to the compensation paid to the CCs. Current models for vehicle routing problem with casual couriers consider a compensation scheme for the couriers where a certain amount is offered for a given task, assuming that CCs will accept that amount and execute the job. A more realistic model must consider some randomness in this process. Several facts should be taken into account: (i) there are no guarantees that a CC will accept the task proposed; (ii) the optimum amount to be offered for a given task depends on the costs incurred by the company, hence depending on the current vehicles' route.

The aim of this work is to tackle the vehicle routing problem with casual carriers with a stochastic approach. We develop a model for the problem and implement an exact method for calculating the expected cost for the company.

3 - Optimization problems in transportation and logistics with crowdsourcing
Katarzyna Gdowska, Ana Viana, João Pedro Pedroso

In sharing and gig economy ride-sharing and crowdshipping are enhanced by technology and monetized in crowdsource based business models: ride-hailing and carpooling were the advent of companies such as Uber or Blablacar, while capacity-sharing and casual deliveries resulted in establishing Deliv or MyWays, among many others. Competitive advantage in crowdserviced transportation and logistics is based on fast and efficient matching, scheduling, and routing tools. It is, therefore crucial to develop new tailored models and efficient optimization techniques that conveniently address the new challenging optimization problems arising in transportation and delivery supported by crowdsourcing. This brings an additional challenge to research in the area, since models and algorithms have to conveniently address problems of escalating scale. The basis are traditional assignment and vehicle routing problems (e.g. pick-up and delivery or dial-a-ride) that are necessarily adjusted to specific features of crowdserviced transportation and logistics. This paper surveys the state-of-the-art on optimization models and algorithms for crowdsouce-based transportation of goods and people. The authors identify the most representative crowdsource-based business models in transportation and logistics, as well as new optimization problems in this domain. In result existing Operations Research problems can be integrated to new research challenges.

■ WB-30

Wednesday, 10:30-12:00 - C007

Advances in Optimization

Stream: Data Science Meets Optimization
Invited session
Chair: *Adam Górski*

1 - On the Optimisation of Monte Carlo Tree Search for No End State Games
Declan Quinn, Edgar Galvan

Monte Carlo Tree Search (MCTS) is a sampling method for finding optimal decisions by performing random samples in the decision space and building a tree. MCTS has attracted the attention of researchers. The main reason for this is due to its major success in the two-player game Go, a game that until very recently was highly difficult for Artificial Intelligence techniques to master. MCTS has predominantly been used in games where there is a well-defined end state that can indicate whether a game was either won or lose in a simulation, which is one of the four basic elements used in MCTS. It easy to see this for any board game with perfect information: the MCTS can simulate a game (e.g., the game of Go) until this game ends returning a reward value e.g., 1 if the game is won, 0 otherwise. However, limited research has been done to address the problem on how to reward a simulation for games where no natural end states are available. In this work, we propose a mechanism to handle such scenarios. We investigate how a reward can be specified based on some heuristics eliminating the necessity of knowing if a game has ended in a win or a loss. To this end, we use the popular video game of Ms. Pac-Man. Unlike other games where MCTS has successfully been used, including the game of Go, Ms. Pac-Man does not have a natural end state. We believe that the proposed approach can be naturally transferred to any other domain where MCTS can be used and where no end natural state exists.

2 - Monitoring and Control of Industrial Processes Using a Unified Machine Learning Approach

Saad Bashir Alvi, Robert Martin, Johannes Gottschling

Keeping an industrial production process in a proper working state requires continuous monitoring, anticipating potential problems in advance, looking for possible solutions to avoid these problems and selecting the most cost-effective solution among available options. Here, we present a unified, machine-learning based approach to these challenges, composed of three phases: a learning phase, a knowledge generation phase and a monitoring and control phase. This approach involves a novel Meta-Prediction function, which is used to generate a sufficiently large database of precomputed prediction values, and combines techniques from predictive and prescriptive analytics to provide practical advice to engineers during the running production process.

Since industrial production processes are composed of many sequential interdependent subprocesses, the proposed framework can be applied to each of these subprocesses to ensure their optimal operation. Particularly, this framework can enable small and medium-sized businesses to utilize the benefits of advanced machine learning methods for process optimization.

The suitability of our methods is demonstrated using industrial datasets from the metal forming and casting industry.

3 - Concurrent Real-Time Optimization of Detecting Unexpected Tasks in IoT Design Process

Adam Górski, Maciej Ogorzałek

Internet of Things (IoT) is consisted of billions devices. Each device is responsible for executing some tasks. When IoT is constructed some unexpected situations can appear. Each situation can be solved in many ways. Therefore it is very important to decide which way is better. In this paper we present a genetic algorithm for selecting number and assignment of unexpected tasks. Such a selection is divided on two phases and made concurrently in-real time. One phase is responsible for choosing the number of a tasks meanwhile the second selects devices to execute each task. Each phase impacts another in real-time.

■ WB-31

Wednesday, 10:30-12:00 - G108

Analytics in healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Petra Apell*
Chair: *Tom Monks*

1 - Development of an algoritmic price for health care services

Christine Huttin

Development of an algorithmic pricing for medical services Prof Dr Christine C Huttin (www.endepusresearchinc Univ AixMarseille)

Following the presentation at Orahs Oslo (July 2018) where consistency issues were discussed for a special application of conjoint models in health care, this step explores some classifiers and approaches from hyper heuristics. The current algorithm, called reversed conjoint , presented in Toronto Medical decision making society in 2010, showed how using special applications developed from psychological models such as the Brunswik Lens models, may help to compare how economics restrain behaviors of physicians and patients in different settings and what tasks may be automated in order to optimize the opportunity costs of time and possibly cost sharing across different diseases and physicians 'profiles. A critical review of cognitive feedback studies from two existing metareviews developed by psychologists on human judgment studies are used (Karelia et Hogarth, Kaufmann et ales)to provide estimate on efficiency of congruence in judgment studies, for clinical and administrative tasks. The studies are reviewed especially with the classification of tasks in familiar versus abstract tasks. Statistical results from the studies are compared with this type of recategorization of tasks in order to examine how familiarity of the context can impact the results. Hyper heuristics methods may be very useful to optimize delivery of affordable care

2 - Modelling shared resources in healthcare

Sumanta Basu, Tania Saha, Balram Avittathur, Conan Mukherjee

In all developing countries, the national health policies envision equitable health services for all sections of the society specifically in rural areas. The rising prices of devices causes a major accessibility concern in addressing healthcare issues in developing countries. This paper analytically explores the concepts of sharing economy by bringing buyers and sellers together through a common platform to tackle accessibility issues, associated operational inefficiencies and economic savings (and consumer surpluses) in healthcare. In our model, OEM sell differentiated versions of the same machine and charge different prices to different hospitals based on the included features. We use an analytical approach to understand whether it is profitable for manufacturers to include a product with lesser quality in their portfolio or does its exclusion leads to demand cannibalization. We formulate conditions under which it is optimal for manufacturers and hospitals to tap the value of the sharing economy and when it is optimal for hospital to buy the lower quality machine. We also discuss the insights related to the impact of price sensitivity, market size, quality impact factor on the equilibrium price as well as profitability and on the socially optimal outcome.

3 - Natural Disasters ahd Health: 2010 chilean earthquake

Valeria Scapini

Natural disasters generate great economic damages. In this sense, the case of Chile is particularly interesting, as it is located in the "Pacific Ring of Fire" and is considered one of the most seismically active countries in the world. Based on the evidence from the 2010 earthquake, an empirical study was carried out using the panel survey "CASEN Post earthquake 2010" and the panel of mandatory denotification diseases provided by the Ministry of Health between 2008 and 2013. A difference in difference model was estimated to determine the effect of the disaster on the number of foodborne diseases. The estimated model shows that after the earthquake, in the area affected by the disaster, 1.35% of the total number of diseases increased. Urban areas show an increase of 1.64% that is higher than the average, while rural areas do not show changes. By type of illness, the results include the relationship between the occurrence of the earthquake and the incidence of salmonella. The main focus of the present study was to investigate potential outbreaks of foodborne diseases and generate evidence for the implementation of health public policies.

4 - Social Contact Network Models for Measles Control Strategies in a Context of Constrained Health Care Resources in Tanzania
Herieth Rwezaura, Seán McGarraghy

Tanzania revaccinates individuals during measles outbreaks, despite having scant healthcare resources. We apply social contact network epidemiological models to simulate the spread of measles and examine which vaccination strategies can effectively control outbreaks. We use demographic and measles surveillance data from rural villages in Tanzania to construct and simulate such networks. We employ a hybrid of existing social contact networks models to develop SEIR simulation models of measles spread. Results strongly indicate the spread of measles largely depends on contact rates among infected individuals within a population. Sensitivity analysis on simulation model parameters shows that a measles epidemic with a shorter latent period and longer infectious period has an earlier and higher peak in the epidemic and a greater percentage of infected people during it, compared to measles epidemics with a longer latent and shorter mean infectious period. Findings indicate a need for targeted vaccination for children of 6 months to 15 years of age, but equally for older age groups who were born before or missed the second dose schedule. This work contributes theoretically and methodologically to existing applications of social contact network models for airborne infectious diseases in areas with health system constraints. It sets out implications for the design of effective vaccination programmes for control of measles in Tanzania and in other developing countries.

■ WB-32

Wednesday, 10:30-12:00 - G109

Models and Algorithms in Medicine: Decision Support Systems

Stream: OR in Computational Biology, Bioinformatics and Medicine
Invited session
Chair: *Metin Türkay*
Chair: *Isabel Mendez Fernandez*

1 - A hybrid simulation model of end-stage kidney service for strategic planning and implementation
Kim-Huong Nguyen

Patients with end-stage chronic kidney disease (ESKD) require renal replacement therapies (RRT) to maintain their health and quality of life. Due to a shortage of kidney donors, dialysis is the main treatment. While many patients can safely dialyse at home, patients often opt to dialyse in clinic. The average annual cost per patient for home and clinic dialysis is approximately AU$50,000 and >AU$80,000, respectively. If clinics are at full capacity, additional acute dialysis chairs are needed at the expense of other services. With rising ESKD rates (5-10% per annum) and limited healthcare resources, it is essential to improve the efficient use of RRT services to meet the demand and maintain high quality of care. In this project, we develop a simulation model to inform RRT service planning of an Australian health district. The model combines agent-based and discrete event simulation methods (using AnyLogic'8) to represent the patient journey through different RRT modalities and their use of healthcare resources and health outcomes (measured by quality adjusted life years). Implementation scenarios to improve the technical and/or allocative efficiency of RRT services are examined, including encouraging patients to choose (i) home over clinic dialysis, (ii) conservative care, where there is limited clinical benefit from dialysis; and the establishment of (i) regular dialysis chairs, (ii) satellite clinics, and (iii) a live kidney donor centre.

2 - An Integrated Decision Support System for Platelet Distribution
Emel Aktas, Mike Roberts, Nicky Yates, Soroosh Saghiri

Platelets are small white blood cells that work with clotting factors in plasma to stop or prevent bleeding. Transfusions of platelets are required for a variety of patient needs, including those undergoing chemotherapy for cancer, receiving organ transplants, or suffering from life-threatening bleeding due to trauma or surgery. As an extremely short shelf life product (less than 7 days), platelet production and distribution require meticulous planning to ensure patient demand is met whilst minimising wastage due to time expiry. Product variation adds further complexity, with 32 platelet variants depending on blood group, rhesus factor, production process, and Cytomegalovirus status. Substitution of variants is possible provided substitution conditions are satisfied. In this work, we build a novel integrated decision support system (DSS) that distributes available inventory across the national stock holding network to meet patient demand whilst minimising wastage due to time expiry. The approach's novelty includes consideration of all relevant the substitution effects and communication with the product management system, taking available stock as input and producing distribution orders as output real-time. The developed linear programming based DSS tool runs every day and redistributes existing and new stock to balance supply and demand. The stakeholders of the system have provided positive feedback on run times and ease of use after the tool is deployed system-wide.

3 - Developing a New Framework to Improve Emergency Departments' Performance; A New Zealand Perspective
Neda Pourreza

In this study, first, we provided a structural literature review to investigate research stream on nursing at emergency departments. Subsequently, we named different factors to identify optimal team composition according between team members to improve not only nurse utilization but also patient's outcomes. Our case study would be the ED of MiddleMore Hospital, the biggest public hospital in Auckland. So, this paper aims to answer the following questions;

- Question one: • How "team composition" lead to improve nurses' outcome in terms of less error and better diagnosis? (Strategies to Make Optimal Team Composition to Improve Nurses' Outcomes) - Question two: • How the optimal team composition (identified in the first question) leads to maximizing patient's outcome in terms of minimizing service time and waiting time? (Strategies to Make Optimal Team Composition to Improve Patients' Outcomes)

4 - A task scheduling problem in a home care business
Isabel Mendez Fernandez, Silvia Lorenzo-Freire, Ignacio García-Jurado, Julian Costa, Maria Luisa Carpente

In this work we present a scheduling problem for a home care business. The company we work with provides healthcare and domestic services to elder and dependent people. To this aim they have a set of caregivers who are in charge of visiting users' homes, in order to carry out the tasks that have been assigned to them. The users set different parameters to the visits, like availability time windows, duration, day of the week, etc. Apart from that, to correctly schedule the visits, the company must consider nurses' contracts, travel times and the fact that users prefer not to have their caregiver changed. To solve this scheduling problem we first propose an integer programming problem but, because the real instances we need to solve are of great size (resulting in a huge number of variables and constraints), we designed an heuristic algorithm that provides good solutions in short CPU times. The heuristic algorithm can be divided into three phases. First, we prepare the initial solution, that is, we select the services whose schedules must be modified (like visits for new users). Second, we assign those visits to the best available caregiver. Finally, the schedule is optimized using the simulated annealing method, in order to obtain feasible schedules while minimizing the time lost between visits. We checked the algorithm's good performance by solving a battery of examples, and comparing the solutions given by the algorithm with those given by the integer programming problem.

■ WB-33

Wednesday, 10:30-12:00 - Q005

Modelling and Optimisation in Logistics II

Stream: Dynamics and Games
Invited session
Chair: Boaz Golany

1 - Modeling and predicting the throughput of stochastic flow lines with limited local buffer capacity via artificial neural networks
Insa Südbeck, Stefan Helber

Flow lines are frequently used to organize the mass production of physical goods in manufacturing. Such a line consists of serially arranged stations that are designed and equipped to perform dedicated tasks. The product units flow through the line to receive a series of operations at those stations. In a deterministic setting, the slowest station is the system's bottleneck and determines its throughput or production rate (measured in product units per time unit). However, in reality processing times are often stochastic, e.g., because of machine failures. In this case, to avoid blocking and starving, costly buffers can be installed between the stations to limit the propagation of failures up- and downstream of the system. In practice, discrete-event simulation is often used to estimate the production rate of a given (planned) flow line configuration. As an alternative, extremely fast approximate analytical methods have been developed to estimate the production rate of stochastic flow lines without using discrete-event simulation. We use such an analytical method to create and evaluate a large number of hypothetical flow lines and then train an artificial neural network to predict the production rate of flow lines which have not yet been analyzed before. We present first results from a systematic study of this new approach for flow line performance evaluation.

2 - Free Shipping and its Direct Causal Effect on Online Sales
Taner Bilgic, Seyhan Erden, Tolga Ahmet Kalaycı

Sales through online marketplaces have been steadily increasing. One of the fundamental differences between traditional and online shopping is the shipping and handling (S&H) operations. Any consumer who uses online shopping starts the transaction with the knowledge that the item needs to be shipped to the consumer at an additional cost (of money and/or time). This fundamental difference seems to have a significant effect on the demand-price interaction for online shopping. We establish that an offer for free shipping is endogenous in several model specifications we consider. Therefore, we use several instrumental variables for free shipping and two stage least squares method as well as panel data. In the panel data we use different sellers and different product sub-categories as the entity variable. Fixed effects methodology combined with two stage least squares, free us from the bias and inconsistency due to endogeneity. Using data from an online marketplace, we show that free shipping can increase sales and revenues significantly. This effect changes by product category. Free shipping increases the unit price of the product but decreases the total price paid by the customer in accordance with previous reports from the literature. We also show that the obtained results are consistently predicted by a causal Bayesian machine learning technique.

3 - Two-Machine Job-shop Scheduling with Aging Effects and Maintenance Activities
Hesham Alfares, Awsan Mohammed, Mustafa Ghaleb

This paper presents models and solutions for a two-machine scheduling problem with position-dependent job processing times subject to both aging and maintenance effects. Aging effects lead to longer processing times of jobs processed later due to machine aging, job deterioration, and workers' fatigue. An aging model is used here in which the actual processing time of each job depends on its scheduled position within the job processing sequence. In contrast, maintenance improves the machine condition, leading to faster job processing times. Scheduled maintenance restores machines to as-new conditions, providing a way to counter-balance the aging effects. Aiming to minimize the overall makespan for the two parallel machines, two cases are analyzed. In the first case, no maintenance is scheduled, and hence the machines are always available during the planning horizon. In the second case, maintenance is scheduled within the job processing sequence, and hence the machines are not available during maintenance times. The problem of simultaneous scheduling of jobs and maintenance activities is generalized by assuming the number and the positions of maintenance stops to be variable. Integer programming models are formulated to determine the optimal number of maintenance stops and the optimal sequence of jobs and maintenance stops on each machine. In addition, an efficient heuristic algorithm is developed to obtain near-optimal job processing and machine maintenance schedules.

4 - A Multi-Product Dynamic Supply Chain Inventory Model Considering Supplier Selection, Joint Replenishment and Transportation Cost
Boaz Golany, Jose Ventura, Abraham Mendoza, Chenxi Li

This paper extends a multi-period inventory single product lot-sizing model in a serial supply chain with multiple suppliers and customers (Ventura et al. 2013) to multiple products. The extension also includes a richer cost structure involving joint replenishment costs for raw material replenishment and production, and a more realistic description of the transportation costs that are now presented as a vector of full-truck load costs for different size trucks. The problem can be viewed as a time-expanded transshipment network defined by the nodes and arcs that can be reached by feasible material flows. An integrated mixed integer linear programming model aimed at minimizing the total cost over the entire supply chain for a given planning horizon is developed to determine the optimal dynamic supplier selection and inventory operational plan simultaneously. In addition, a sequential approach is proposed where an inventory plan is determined first, and a supplier selection and replenishment strategy are obtained according to that plan. Sensitivity analysis comparing the two approaches is performed. Results show that even though the integrated approach produces the minimum total cost, the sequential approach may be suitable for solving large-scale instances of the problem as it requires less information sharing and generates a near-optimal solution with less implementation time and computational effort.

■ WB-35

Wednesday, 10:30-12:00 - Q009

Healthcare in disaster situations

Stream: Healthcare Logistics
Invited session
Chair: Marion Rauner

1 - A Simulation-Optimizer for the New Austrian Advanced Medical Post (AMP): Investigating Different Realistic Policy Disaster Scenarios
Marion Rauner, Simeon Beile, Helmut Niessner

Policy makers are confronted with an increasing number of complex and unique mass casualty incidents. Thus, we developed a discrete event simulation-optimization policy model which has been applied by the Austrian Samaritan Organization to support planning of ambulance resources at the incident site to set up an Advanced Medical Post (AMP) for triaging, treating, and transporting patients. We adapted our initial policy model to account for the latest organizational changes. In the past, either the mean total number of fatalities or the mean total rescue time for patients could be optimized. To better balance these often contradicting optimization goals, we provide the mean health status of severely injured patients as an additional optimization option. To better investigate differences among the scale and scope of disaster policy scenarios, we refined the input of the distribution for the health status of severely injured patients in the scenario setting. We investigate in detail a variety of realistic predetermined disaster policy scenarios. We illustrate that scheduling guidelines for triaging, treating, and transporting of patients at the incident site as well transporting of patients to hospitals vary both among the optimization goals and different disaster policy scenarios. These findings enable disaster policy makers to best prioritize scarce resources for certain positions and their related queues at the Austria AMP.

2 - A mathematical modeling approach for managing blood bank operations
Ozlem Karsu, Metehan Dilaver, Benhür Satir

Blood bank operations involve supply chain management of highly perishable goods such as whole blood and blood products. The Turkish Red Crescent (TRC) is the main responsible organization in Turkey for collection, testing, separation and distribution of whole blood and blood products. We propose a mathematical modeling approach for managing the blood bank operations in the TRC that include the decisions of donation collection, testing, production and distribution to demand points. The model minimizes system cost while ensuring maximum level of demand satisfaction. For this purpose, a lexicographic approach is used that first determines the maximum amount of demand that can be satisfied and then solves a cost minimization model, which is a linear mixed-integer programming model. Observing that it may not be possible to find the optimal solution of this model in reasonable time for some real-life problem sizes, we develop a customized heuristic approach. We demonstrate that the heuristic algorithm provides good quality solutions in reasonable time through computational experiments.

3 - Preparedness for a flu pandemic: modelling an intensive care unit
Honora Smith, Dandan Shi, Christine Currie

As part of a wider study of the Bristol Royal Infirmary (BRI) adult intensive care unit (ICU), a study was made of the ICU's ability to cope with pandemic conditions. Estimates of numbers of patients coming from the South West region of the UK were made using the literature, for mild, moderate and severe pandemics. Of particular interest was the effect that an influx of numbers of critically ill patients would have on the normal workings of the ICU. Delays in boarding patients can lead to longer ICU stays and higher mortality. Discrete event simulation was used to model delays that might be incurred, and to determine how long the ICU would be affected. It was assumed that staffing levels would be affected by a pandemic. Findings are that the ICU could only cope with the numbers expected in a mild pandemic, but not higher numbers, and that the ICU would take at least double the expected length of the pandemic to return to normal operations.

■ WB-36

Wednesday, 10:30-12:00 - Q010

Stochastic Vehicle Routing Problems

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: Constantinos Karamatsoukis

1 - Vehicle routing with stochastic demands: first insights of a real-life case
Silia Mertens, Kris Braekers, An Caris

The Vehicle Routing Problem (VRP) has already been widely studied in literature. The main focus is however on deterministic VRPs. Nevertheless, different forms of uncertainty can occur in real life, such as stochastic demands, customers, travel times and service times. Uncertainty in demand is the most common. In this work, a case study is presented in which customer demands are uncertain. The company under study is a logistics service provider who serves different customers in Europe. Customers have to submit transportation requests in which they have to specify their orders that need to be collected. However, when arriving at the customer, often deviations between the actual quantities and the specified quantities are observed. Furthermore, customers are free to specify their orders, for example, in volume, real weight or dimensions. Yet, the planning in the company is made up in load meters, so orders needs to be translated in the correct load meters, which is not an easy task. This makes it difficult to make a good routing plan. This work tries to provide insights by looking at patterns in historic data. Routing plans based on initial and real orders are compared and, based on these insights, a stochastic VRP will be studied.

2 - A Multi-Agent-System for the Dynamic Periodic Multi-Depot Open Vehicle Routing Problem with uncertain demands in the context of emergency logistics
Stephan Hocke, Jörn Schönberger

There is no doubt that one feature of the Anthropocene is the increase in climatic weather extremes. More frequent and stronger hurricanes, deluges, tornadoes, blizzards and floods are just a few examples with immediate consequences for the victims. If agglomerations are affected, an efficient aid service is faced with a logistical mammoth task. Innumerable requests for help must be served. Online-Information about the advance of the disaster are received every minute in the operation centers updating the picture of the overall disaster scenario. Often, on-site relief requires the delivery of man power as well as material to spots scattered of the disaster area. Thereby, vehicles are an essential ingredients to provide the urgently required help. This paper presents a mixed integer programming model for the corresponding Dynamic Periodic Multi-Depot Open Vehicle Routing Problem with uncertain demands. Since optimization in the context of catastrophe management usually includes an ethical dilemma, we propose a Multi-Agent-System to depict a negotiation process of the emergency services and the affected inhabitants. This means that the task forces strive to maximize the overall service level, whereas those affected want to be supplied as quickly as possible. To test our algorithm we created a realistic flooding scenario for Dresden based on Geo-Information obtained from previous flood events of the city, which includes an update of the underlying road network in each period.

3 - An optimal routing strategy for the collection of two similar materials with stochastic continuous demands
Epaminondas Kyriakidis, Theodosis Dimitrakos, Constantinos Karamatsoukis

A vehicle visits N ordered customers in order to collect from them two similar materials. It is assumed that the quantities of the materials that are collected are continuous random variables. Each customer has only one type of material. When the vehicle arrives at a customer's site, the type of the material that he/she possesses and the actual quantity that must be collected are revealed.The vehicle has two compartments with same capacity. Compartment 1 is suitable for loading Material 1 and Compartment 2 is suitable for loading Material 2. If a compartment is full, it is permissible to load the corresponding material into the other compartment. In this case penalty costs are incurred. A dynamic programming algorithm is developed for the determination of the optimal routing strategy that minimizes the total expected cost among all possible strategies for serving all customers.

4 - A clustered two-compartment vehicle routing problem with simultaneous pickup and delivery and discrete random demands
Constantinos Karamatsoukis, Epaminondas Kyriakidis, Theodosis Dimitrakos

We consider a variant of the classical capacitated vehicle routing problem in which the customers are partitioned into clusters and then in each cluster, the customers are served according to a predefined order. This decomposes the problem into two subproblems, i.e. the partition of the customers into clusters and the routing in each cluster. It is assumed that each cluster must have been served completely before the vehicle goes to the next cluster. The vehicle delivers new products and picks up expired products which are stored in two different compartments, in compartment 1 and in compartment 2, respectively. The demands for new products and the quantity of the products that is collected are discrete random variables. It is assumed that the vehicle is allowed to return to the depot to restock with new products and unload expired products. A dynamic programming algorithm is developed in order to find the optimal routing strategy. Numerical results are also presented for the problem we study.

■ WB-37

Wednesday, 10:30-12:00 - Q011

Markets and auctions: analysis and design

Stream: Mathematical Models in Macro- and Microeconomics

Invited session

Chair: *Alexander Vasin*

Chair: *Gerhard-Wilhelm Weber*

1 - The sensitivity of commodity markets to exchange operations such as swings

Galina Bobrik, Irina Sukhorukova, Petr Bobrik

A pricing model for the simplest commodity markets is considered. The model describes the behavior of the Order Book, consisting of orders from producers and consumers only. If the number of asks or bids is not enough in comparison with the volumes planned by the traders, then producers and consumers, respectively, shift their orders in the direction of the current price at some speeds, and thereby achieve the necessary number of transactions per unit of time. Moreover, these speeds depend on the volumes of supply and demand. They must support the supply-demand balance. The paper explores the external impact on this model in the form of large operations by new market participants, who at high speeds begin to push forward their orders, for example, first bids and then asks. Such strategies are called swings. This paper simulates a single cycle of one simple trading strategy of the swing type. This example shows that the simplest commodity markets with producers and consumers have the internal property that they are potentially vulnerable to external influences. The swinging of prices through large purchases and sales leads to systematic profits of the entrants at the expense of the traditional market participants.

2 - Energy markets: optimal transmission expansion planning

Olesya Grigoreva, Alexander Vasin, Nikita Tsyganov

Markets for energy resources usually include own transmission networks. We consider the welfare optimization problem, taking into account the production costs, consumer utilities and the costs of transmission capacities increment. The problem is NP-hard under positive fixed costs of transmission lines expansion. We provide a method for optimization of star-type networks based on the concepts of competitive and complementary network lines. We confirm its efficiency by the results of a computation experiment. In addition, we consider a method of the supply-demand balances transfer to the root node. The method provides a solution of the auxiliary problem with zero fixed costs of the lines' expansion. We consider a modification of the method in order to obtain an approximate solution and evaluate the error. The problem of the optimal development of the transmission system till a given planning horizon is also considered, and we reduce the problem to a finite set of convex auxiliary problems.

3 - Fair Water Management Cost Allocation in Shale Gas Industry

Alba Carrero, Vivek Dua, Lazaros Papageorgiou

The rapid growth in shale gas production is changing the global energy market. Accordingly, an increasing number of companies are extracting gas in the same shale play in the last years. Therefore, if companies placed in the same shale play are forced to work together in water management or shale gas extraction and distribution, it could be possible to reduce total costs. In this work, we focus on the analysis of optimal water management strategies among shale companies. These strategies include recycling water among different well pads, freshwater withdrawal decisions, or sharing onsite water treatment technologies. In this situation, the question arises in how to address a fair water management cost distribution among the shale gas companies. To do that, we apply a Nash bargaining solution method based on non-cooperative game-theory, in which player's individual strategies and bargaining payoff are analysed computing the Nash equilibrium. A mixed integer non-linear programming (MINLP) model is proposed to determine the optimal water management strategies among several shale gas companies. First, a small numerical example comprising of 30 well pads belonging to 3 different companies is analysed. Then, a separable programming approach is implemented to solve effectively a larger case study comprising of 14 companies. This is achieved by reformulating the initial MINLP as a mixed integer linear programming (MILP) problem.

4 - Optimal timing of First-Price Auctions with R&D Races

Ruben Martinez Cardenas, Nick Huberts

We analyze a revenue maximization allocation mechanism for an good whose value is time dependent, and where bidders incur in pre-implementation investments to improve their position at both implementation and exercise times. Firms invest in R&D to improve their position, which is solved by means of optimal control theory. In the auction mechanism studied bids are formed by two components: cash and a security. We characterize optimal investment and bidding behavior for symmetric firms, and the optimal implementation time for the mechanism. Results show R&D investment intensity levels are non-monotonic with respect to firms' types when the number of participants is relatively small. However, as the number of bidders becomes large, more efficient firms at the time of the announcement lead the bidding strategies. Allocation delay can improve future expected revenue when the securities effect dominates the value of the cash component in the bid. This later outcome results in implementation delays that can lead to inefficiencies, however, it can also increase social welfare via gains in production efficiency.

■ WB-38

Wednesday, 10:30-12:00 - Q012

MCDA and Environmental Management 2

Stream: Multiple Criteria Decision Aid

Invited session

Chair: *Luisa Paolotti*

Chair: *Filippo Fiume Fagioli*

Chair: *Lucia Rocchi*

Chair: *Antonio Boggia*

1 - Exploring Gender Differences in Attitudes toward Air Pollution Based on Social Media Mining and MRDM Methods

Chia-Lee Yang, Chi-Yo Huang, Ching-Chun Hsu, YiHao Hsiao, Yu-Tai Wang

Air pollution is one of the most concerned environmental issue due to the contaminants in the air which can disturbing human health or welfare or generating other harmful environmental impacts. Although the effects of air pollutions are harmful, people's attitudes toward towards global environmental phenomena varies. According to past works, females are more sensitive and active than males regarding to environmental impacts, and are more willing to act environmentally for a variety of reasons. This study aims to identify the gender differences regarding to air pollution based on text mining, topic modelling, and multiple rule decision making methods consisting of the Dominance Based Rough Set (DRSA), and the Decision-making Trial and Evaluation Laboratory (DEMATEL). The text mining techniques and the topic modelling technique are first introduced to derive topics from social networking sites. An inter-topics matrix consisting of keywords as condition variables and genders as decision variables will be constructed based on the text mining results. Then, the "if ... then" inference relationships can be derived by using the DRSA. All the cause-effect relationships among the topics can be derived. The most interested topics by different genders can thus be derived. The proposed data-driven approach which combine big data analytics and MRDM methods can service as the guide for environmental policy definitions.

2 - The evaluation of territorial sustainability in the framework of the United Nations Sustainable Development Goals (SGDs)

Antonio Boggia, Luisa Paolotti, Filippo Fiume Fagioli, Lucia Rocchi

At the Sustainable Development Summit of 25-27 September 2015 held in New York, the United Nations General Assembly adopted the document: "Transforming our world. The 2030 Agenda for Sustainable Development ". With Agenda 2030, the guidelines of the activities for the next 15 years and the commitments for sustainable development to be carried out by 2030 are outlined, identifying 17 Objectives (SDGs - Sustainable Development Goals) and 169 targets. The 17 Sustainable Development Goals represent the United Nations global action plan to eradicate poverty, protect the planet and ensure prosperity for all. The SDGs have a universal character - they address both developing countries and advanced countries - and are based on the integration of the three dimensions of sustainable development (environmental, social and economic), as a prerequisite for eradicating poverty in all its forms. In our work, we selected a pool of indicators in the framework of SDGSs, from a more extensive dataset collected by the Italian National Statistics Institute, and we applied a model for evaluating territorial sustainability through a multicriteria methodology. The model (GeoUmbriaSUIT) integrates MCDA with GIS and is able to evaluate the three dimensions of sustainable development at territorial level. It was developed in its version in 2007 (without the integration with GIS); after the version 2.0 (in 2013) it has now arrived to version 3.0.

3 - From the farm to the agri-food system: a multiple criteria framework to evaluate extended multi-functional value

Filippo Fiume Fagioli, Lucia Rocchi, Luisa Paolotti, Roman Slowinski, Antonio Boggia

Multi-functionality has an impact on the economy, the environment and nature, and constitutes a path to sustainable development. The dimensions of multi-functionality are interpreted in literature in many different ways, but they always deal with environmental, social and economic aspects. The measurement of the multi-functionality of the agri-food system is an important issue, as it allows the value chain to be interpreted under the lens of sustainable development pillars. In this work, we argue that multi-functionality is a value, which extends its benefits along the entire agri-food chain. We present a methodology to aggregate indicators into an evaluation framework, in order to assess the level of multi-functionality along the entire food value chain. We have called this the "extended value" of multi-functionality, since our approach is able to consider not only the farm level, but also extends to the entire food chain. A Multiple Criteria Decision Aiding (MCDA) methodology was used to implement an evaluation process by assigning specific importance to each indicator. This process aggregated the evaluations of multiple indicators into an integrated interpretation, and aimed to support policy makers by providing a ranking of alternative ruling policies for the agri-food value chain. We finally tested our methodological approach on a case study concerning an agri-food value chain for different European countries.

4 - Multicriteria Decision Support Approaches for Physiotherapy Under Uncertainty

Melodi Cebesoy, Ceren Tuncer Sakar, Barbaros Yet

Because of the aging population in Turkey, treatment of musculoskeletal diseases has become an important issue. Effective treatments should be selected, but the limited healthcare resources in Turkey should also be considered. With this purpose, we develop a decision support model to assist doctors and physiotherapists, and also to offer advice to patients. There are several criteria that should be incorporated to the process of selecting a treatment alternative for a patient. These criteria include pain, cost, inconvenience for the patient and side effects. Therefore, we use Multicriteria Decision Making approaches to decide on the best treatments for patients. However, since the outcome of a specific treatment cannot be known in advance with certainty, treatment alternatives have probabilistic outcomes in some criteria. We use Bayesian Networks to derive the probability distributions of criteria outcomes for each treatment alternative. In order to work in this uncertain environment, we make use of Monte Carlo Simulation and generate a large number of discrete scenarios on criteria outcomes. After the generation of scenarios, we apply PROMETHEE I and II to obtain partial and complete rankings of alternatives. Special procedures are developed to arrive at final decisions from the scenarios. The proposed approaches are illustrated on an example problem with several alternatives and criteria.

■ WB-39

Wednesday, 10:30-12:00 - Q014

Educational timetabling

Stream: Timetabling
Invited session
Chair: *Ayla Gülcü*
Chair: *Can Akkan*

1 - Minimum Penalty Perturbation Heuristics for Curriculum-based Timetables Subject to Multiple Disruptions

Can Akkan, Ayla Gülcü, Zeki Kus

Course timetables are often rendered infeasible due to unexpected changes in requirements and must be repaired. Given an initial timetable, planners prefer a repaired timetable whose quality is worsened as little as possible while its structural difference is also as little as possible. This paper formulates this problem as one of minimizing the quality degradation subject to an upper limit on the structural difference and presents one simulated annealing algorithm and a set of integer programming-based algorithms to solve it. These algorithms are tested on instances comprised of the ITC-2007 curriculum-based course timetabling test-bed and a set of randomly generated disruption scenarios, where each disruption scenario is based on a set of four disruption types that affect period and room availability. The results are analyzed with respect to two main goals, one being repairing a timetable after single disruption scenario, and the other being the calculation of an estimated robustness of a solution based on a sample of disruption scenarios.

2 - System for Preparing Institute Timetable: Practical issues in timetabling for a university

Mustafa Vora, Ashutosh Mahajan, Jayendran Venkateswaran

We describe a practically feasible system developed at IIT-Bombay for planning timetables for regular classes and exams. Courses to be offered in a semester are decided by various departments. Large courses that are required by students across several departments are scheduled first by the central timetable coordinator. For other courses we have a distributed decision making process where department's timetable coordinators and a central coordinator work together. For each course we have to make two decisions: (i) Allocating a time-slot: It is left to departments to decide the time-slot for each course, and (ii) Allocating a room: For busy slots central coordinator assigns the room and for other slots rooms are assigned in first-come-first-served fashion. Once a room is assigned to a course our system does not allow any other course to be assigned in the same slot. We have developed a web-based interface for the above procedure and used it for last four semesters. Exam-timetabling is done after regular timetable is released. The system here is more central where central coordinators assigns various course-groups to an exam-slot using an integer programming formulation. We solve the integer program with the objective of reducing the number of back-to-back exams. After the slot decisions are made, rooms are allocated to the departments based on the number of students taking the courses.

3 - A simultaneous sequencing and allocation problem for military pilot training: integer programming approaches
Vicky Mak

In this paper, we study a unique combinatorial optimization problem that arose from army helicopter aircrew training. Each pilot trainee has to complete a sequence of courses and these courses have a pre-requisites structure. There is a pass rate associated with each course. Each course has a number of repeated sessions with the same time span but occupying a different set of time slots. A feasible schedule is a sequence of course sessions such that each course in the syllabus is covered by exactly one session, and that all pre-requisites requirements are observed. The optimization problem is to simultaneously assemble course sessions to form feasible schedules, allocate students to these schedules with an objective to minimize the total time-span in completing the syllabus over all students, while ensuring that the class size restrictions for each course session is observed. The problem is fundamentally different from the school or university time tabling family of problems and is also fundamentally different from the Generalized Vehicle Routing-Family problems. We formulated and tested three integer programming models. The first two are polynomial-size arc-based formulations defined on a digraph. The third approach is a schedule-based ILP and contains exponentially many variables (columns). These columns are generated using two approaches: 1) a revised Knuth's Dancing Link Algorithm for complete enumeration, and 2) Column Generation.

■ WB-40

Wednesday, 10:30-12:00 - Q015

Integrated Routing Problems I

Stream: Vehicle Routing and Logistics Optimization II
Invited session
Chair: Elmar Swarat

1 - Exact and Heuristic Solution Procedures for the Backhaul Profit Maximization Problem
Eli Olinick, Yuanyuan Dong, Yulan Bai, Andrew Yu

In the backhaul profit maximization problem (BPMP) a freight carrier seeks to generate revenue from an empty delivery vehicle's backhaul trip from its last scheduled delivery to its depot by allowing it to deviate from the least expensive (or fastest) route to accept delivery requests between intermediate points as allowed by its capacity and required return time. We present a compact mixed integer program (MIP) for the BPMP inspired by a novel representation of multicommodity flow that significantly reduces the size of the constraint matrix and the linear programming upper bound on optimal profit compared to a formulation based on the classical node-arc representation. This in turn leads to faster solution times when using a state-of-the-art MIP solver. In an empirical study of both formulations, problem instances with 40 potential pickup/dropoff locations (including the vehicle's current location and its depot) and 1,482 delivery requests were solved 600 times faster on average with our formulation. The largest instances in the study had 50 locations and 2,352 delivery requests; these instances could not be solved with the node-arc-based formulation, but were solved within an average of 40 minutes of real time using our compact formulation. We also present a heuristic algorithm that finds near optimal solutions to the 50-location instances within a few minutes of real time.

2 - An Integrated Routing and Scheduling Problem: Application in Service Delivery
Marina Vinot, Philippe Lacomme

Scheduling and routing problems are particularly important in world with an increasing global competition. In order to ensure a good quality of service in healthcare problems and more generally in service delivery problems, joint optimization of several issues must be developed. The RCPSPR (RCPSP with Routing) is an integrated problem based on the extension of the RCPSP (Resource-Constrained Project Scheduling Problem) where resources must be transported from one activity to another using a vehicle. This problem deals with two interrelated problems, a scheduling problem (RCPSP) and a routing problem (VRPPD), and belongs to the family of integrated problems. The RCPSPR is solved by Lacomme et al. in 2017 using a resource flow. A new graph flow is proposed in this paper, by allowing the vehicles to transport an amount of resource exceeding the demand of the destination activity with multiple-capacity vehicles. The extra resources transported can either be delivered and stored on the activity or kept in the vehicle to be delivered in another activity. The proposed approach to solve the RCPSPR problem with these new constraints is based on a new flow graph and on a split algorithm to define the routes of vehicles in the solution. Local search tools are also set up, including pattern recognition within the solutions. The new solutions of the RCPSPR prove that the makespan can be significantly reduced, by avoiding costly transportation operations.

3 - Crew rostering for Toll Enforcement - Efficiency and employee friendliness
Elmar Swarat

We present an IP approach for a personalized crew rostering problem. The problem is to optimize mobile control tours for toll enforcement inspectors on German motorways and main roads. Their task is to enforce the proper paying of a distance-based toll for all trucks weighting 7.5 tonnes or above. In addition, feasible rosters of the inspectors need to be generated. This leads to an integrated tour planning and duty rostering problem; it is called Toll Enforcement Problem (TEP).

We tackle the TEP by a standard multi-commodity flow model with some extensions in order to incorporate the control tours. We will discuss several aspects of the model. On the one hand different objectives for the control tours since both expected traffic volumes as well as evasion statistics from the past are considered.

Beside the efficiency of the control employee related aspects become important. We will consider different approaches how to distribute undesirable duties in a fair fashion among the inspectors and how uneven duty sequences can be penalized by soft constraints. We will present computational results for real world instances indicating that employee friendly rosters can be achieved with almost no loss of control quality. In addition the influence of employee related aspects on the solvability of typical planning scenarios is evaluated.

4 - A study of fairness objectives as incentive for collaboration between carriers
Adria Soriano, Margaretha Gansterer, Richard Hartl

Many attention has been drawn in the last years towards collaborative transportation schemes. This collaboration must provide enough incentives to each participant to take part on the collaboration. Apart from bringing economic benefits, a sense of fairness in the distribution of work and gains is needed to keep all parties engaged. However, when the transportation plan is provided by a central third-party entity, this sense of fairness can be difficult to achieve. Research has traditionally approached this issue by studying profit sharing mechanisms, in which economic benefits or resource utilization is redistributed a posteriori. In some cases, this mechanisms might pose a strong barrier for entering a collaboration scheme, making an agreement between parties hard to get. In these cases, guaranteeing a fair solution as starting point before any kind of post-optimization mechanism is applied can generate more confidence and reduce uncertainty between parties, which would be more willing to enter an agreement. In this work we study the effects of including fairness in the objective function during the optimization phase, assuming inexistent post-optimization reallocation mechanisms. We take a multi-objective optimization approach and obtain the Pareto frontier for different classes of instances and fairness measures, with the goal of finding interesting compromise points for all parties in the collaborative transportation network.

■ WB-41

Wednesday, 10:30-12:00 - Q013

Optimization in Transportation and Logistics

Stream: Public Transportation I
Invited session
Chair: Valentina Cacchiani

1 - Vehicle Routing Problem in Urban area: optimize costs by mitigating environmental impact
Carmine Cerrone, Anna Sciomachen, Raffaele Cerulli

In this paper we face the problem of delivering a given amount of goods in urban areas arising from e-channel department stores, with the aim of minimizing the overall distribution costs [1]. Costs considers traveling components, loading and other operative aspects, environmental issues. In the business to consumer distribution problem, we have to determine the fleet of not homogeneous vehicles (trucks, wagons, vans, picks-up) to be used for satisfying the demands of clients coming from e-channels, and their related itineraries, given the traveling limits imposed by the urban government. We have to respect the maximum route length constraints and the use the appropriate vehicles for each kind of street. We proposed some variations to the traditional algorithms, in which we include the estimates of environmental costs in real scenarios. This increases the value of the global f.o. but allows a more realistic cost estimate that includes not only the internal costs involved in the problem, but also the related environmental externalities. Preliminary results of test bed cases related to different sized urban distribution networks are reported and analyzed.

[1] R.Cerulli, R.P.Dameri, R.P., A.Sciomachen, Operations management in distribution networks within a smart city framework. IMA Journal of Management Mathematics, V.29, 2, Pp. 189-205, 2018

2 - The Hotspot Problem with peak and off-peak capacity constraints
Giorgio Sartor, Carlo Mannino

In Air Traffic Management, a hotspot represents a region of the airspace in which too many airplanes are scheduled to fly through. The Hotspot Problem (HP) consists of determining new departure times for all flights involved in at least one hotspot, such that the total delay accumulated by these flights (in respect to the original schedule) is minimized and the new schedule is hotspot free. The recently developed Path&Cycle formulation has been shown to perform well when solving HP using an ad-hoc row generation algorithm. We present an extension of such formulation that considers a more generic definition of hotspot. In particular, the number of airplanes flying through a certain region of the airspace is not simply counted at any point in time, rather it is counted within a sliding window of time. By changing the width of the time-window, one is able to differentiate between a peak (small time-window) and off-peak (large time-window) restriction on the number of flights. Moreover, constraints with different time-window widths can be incorporated together into the model. This should better fit with the definition of the workload for air traffic controllers, which is usually based on both peak and off-peak load capacity. The two formulations are then compared on synthetic (but realistic) data.

3 - A real-world demand-responsive mine supply chain model
Shiqiang Liu, Andrea D'Ariano, Mahmoud Masoud, Debiao Li, Peng Wu

In the proposed demand-responsive mine supply chain model, the overall mine stockpile management includes the following main components: demand-responsive time windows; the tonnage of materials in each time window; types and grades of materials; the expected lead time; the due dates; the demurrage weighting factors; the service level; the safety stock level; and the reorder level; the quantity of a commodity (ore) type produced in each period; the quantity of one commodity type supplied in each period, from each mine to each port terminal; the quantity of one commodity type shipped in each period at berths; and the total inventory cost at mines and port terminals. In addition, operational excavating, haulage, and railing performance interactively determine the demand-satisfaction level and stocking levels of numerous stockpiles. Based on the analysis of the above real-world conditions, a novel multiple-echelon, multiple-commodity extraction-haulage-processing-stockpiling-shipment network flow model is developed for optimising a mine supply chain with synchronisation of autonomous mining operations.

4 - Dynamic bus schedules for optimal bus bunching and passenger waiting times
M Venkateswararao Koppisetti, Veeraruna Kavitha

In a bus transportation system, the time gap between two successive buses is called headway. When operating headways are small (high-frequency routes), any perturbation (e.g., in the number of passengers using the facility, traffic conditions, etc.) makes the system unstable, and the headway variance tends to increase along the route. Eventually, buses end up bunching, i.e., they start traveling together. This results in inefficient service and is one of the critical problems faced by bus agencies. Another important aspect is the expected time that a typical passenger has to wait before the arrival of its bus. The bunching phenomenon might reduce if one increases the headway. However, this can result in unacceptable waiting times for the passengers. We precisely study this inherent trade-off and derive a bus schedule optimal for a joint cost which is a convex combination of the two performance measures. We derive the stationary (constant headway) as well as the transient (trip-dependent headway) policies. We pose this as a finite horizon control problem; obtain the optimal policy by solving relevant dynamic programming equations, which lead to an easily implementable algorithm. We obtained the Pareto frontier of the two performance measures by using this algorithm with different tradeoff parameters. We also showed that the optimal among time-varying headway policies performs substantially superior to constant optimal headway.

■ WB-42

Wednesday, 10:30-12:00 - Q113

Intelligent and Sustainable Solutions for Transportation and City Logistics II

Stream: Transportation
Invited session
Chair: Sang Won Kim

1 - Online route planning in response to non-recurrent traffic disturbances
Oskar Eikenbroek, Martijn Mes, Eric van Berkum

Actual traffic conditions substantially influence the timeliness of home deliveries. Route plans can account for recurrent traffic disturbances since these variations show repetition with respect to time and space of occurrence and corresponding network-wide impact. Non-recurrent disruptions, however, show seemingly random behavior with respect these aspects. To assure a reliable delivery process, route plans should not only adapt to incidents that occur during execution, but also anticipate on future conditions that emerge from these incidents.

In this paper, we propose and evaluate an online re-planning method that reduces the impact of non-recurrent traffic disturbances. We use real-time traffic information to detect incidents and anticipate on future network-wide traffic speeds. We propose and implement three main solution strategies for this Dynamic Vehicle Routing Problem: intra-route switching of trips, intra-route switching of customers, and inter-route helper actions that transfer goods between delivery vehicles.

We evaluate our solution method on a real-world example. We evaluate the proposed solution strategies independently and combined, using different prediction horizons with respect to the network-wide travel speeds. Numerical results show that we can significantly reduce the number of time-window violations using our online solution approach compared to a robust offline method.

2 - GAMS - A Generic Analysis Tool for Evaluation of Modal Shift
Birgit Mösl, Nikolaus Furian, Dietmar Neubacher

Infrastructure planning of transport and mobility is a very complex and challenging issue for planners and decision makers. Sustainable decisions have to be made in order to meet current and future needs. Especially in urban and suburban areas, it emerged that focusing on the traffic infrastructure is not sufficient to generate sustainable solutions.

The intention of the developed model is to illustrate the impact of mobility planning decisions on people's mobility behavior and to demonstrate the appropriate functionality and feasibility. First, all requirements were gathered and systematically analyzed. The next steps of the simulation study were: conceptual design, creation of a prototype version, implementation and validation in a selected use case.

The developed generic tool GAMS offers policy makers a possibility to evaluate current and planned strategies in the field of suburban and urban mobility. The model combines extrinsic factors like traffic infrastructure, traffic behavior, hubs with individual decision making. Compared to existing tools for the evaluation of mobility, it should be emphasized that a stronger focus on individual behavior is included in the model. It enables the prediction of mobility behavior at a macroscopic level, creating a virtual environment to evaluate short-, medium- and long-term infrastructure measures as well as funding decisions taking into account individual, regional conditions and developments.

3 - Wider Impacts of Transport Projects: Crossrail 2 Case
Ebru Voyvoda

This study follows the literature that utilizes a more hybrid approach to grasp the heterogeneity among different agents in an urban context. Such an integrated approach can handle impacts of transport policies comprehensively, while simultaneously capturing the behavioral heterogeneity of different agents. This is achieved by adding model components capturing key theoretical elements of discrete choice theory into an applied general equilibrium model. "Full integration", where all blocks of models run simultaneously to find an equilibrium, makes distinct this study from the similar ones. We integrate an applied general equilibrium model with a Discrete Choice Theory based Household Choice Model and a Wardropian Transport Model within a single mathematical framework. All three models run simultaneously to find equilibrium values for prices (consumption goods, housing rents, factors), consumption levels, local populations, traffic flows on the transport network and the modal split.

This model is applied in London to evaluate wider impacts of accessibility change due to the planned Crossrail 2 project, which aims at connecting North and South London rail systems. London Travel Demand Survey (LTDS) micro-data for the year 2014 is used as the primary data source in the analysis.

Model results show that rental price would increase significantly in certain boroughs where the project improves the public transport accessibility.

4 - Empirical Investigation on the Range Anxiety for Electric Vehicles
Sang Won Kim

Although Electric vehicles (EVs) are an important technology for curbing the carbon footprint of road transportation, mass adoption of EVs has yet to happen in major auto markets. Among the major shortcomings of EVs on the market is the limited range and long recharging time, creating psychological concerns to drivers called range anxiety and making them reluctant to adopt EVs. In this work, using a novel data set collected from an on-demand car sharing system, we empirically identify and quantify the effect of a car's effective driving range on its attractiveness to drivers on a single-trip basis, and contrast the findings for EVs with those for traditional combustion engine (CE) vehicles. We conduct three complementary econometric analyses i) to identify drivers' aggregate preferences on fuel type; ii) to show that a key attribute that may account for such difference is the range; and iii) to quantify drivers' preference for longer range by evaluating the trade-off between a car's fuel level versus the cost of access. Our estimates suggest that EVs substantially decrease the service demand (by 20 25%) and the fuel level has a statistically significant effect on the demand rate only for EVs: a 10% increase in fuel level enhances the probability of rental by up to 4% for an EV. Moreover, we find that drivers renting EVs are willing to walk up to forty times as far as they would do for CEs for the same amount of additional range even when they are making very short trips.

■ WB-43

Wednesday, 10:30-12:00 - Q114

Facility location: multiobjective models

Stream: Location Analysis and Optimization
Invited session
Chair: *Javier Alcaraz*
Chair: *Glaydston Ribeiro*

1 - Facility Location Models: Applications of Multi-Criteria Decision Making Methods
Sahar Validi

The structure of the logistics network is affecting the overall performance of supply chains. This designing task is very complicated and its complexity increases when uncertain internal and external factors are involved. Developing an optimisation model that captures all of the factors affecting the network is extremely difficult. Consequently, solving such a model is difficult. This complicated task needs to consider different criteria and take into account different stakeholders priorities Facility Location, with its wide range of integrated problems, and Multi-Criteria Decision Making (MCDM) are both established subject areas within the main domain of Operational Research. Review of literature reveals some applications and contributions of MCDM methods to designing logistics and supply chain networks. This paper, as a part of an ongoing research, aims to review and categorise the applications of MCDM methods in modelling, solving and analysing phases of location decision making within logistics and supply chain networks.

2 - Bi-objective model for optimal size and shape of a finite size facility
Masashi Miyagawa

This paper presents a bi-objective model for determining the size and shape of a finite size facility. The objectives are to minimize both the closest and barrier distances. The former represents the accessibility of customers, whereas the latter represents the interference to travelers. The total closest and barrier distances are derived for a rectangular facility in a rectangular city where the distance is measured as the rectilinear distance. The analytical expressions for the total closest and barrier distances demonstrate how the size and shape of the facility affect the distances. The model focuses on the tradeoff between the closest and barrier distances, and the tradeoff curve provides alternatives for the size and shape of the facility.

3 - A multiobjective support unit location problem to assist roadside traffic survey with multi-stages
Glaydston Ribeiro, Marcus Camara, Thayse Ferrari

Annual average daily traffic (AADT), origin-destination (O-D) trip tables and socioeconomic data are important to transportation planning. Thus, transportation planners can use traffic counts and roadside surveys to estimate, for example, O-D trip tables. In large countries, such as Brazil, roadside traffic surveys require a complex planning and high financial resources. Recently a large traffic survey with 300 traffic counting stations were carried out in Brazilian highways using military platoons to perform counts and O-D interviews with the drives. However, due to the large number of people involved, this survey was divided into four stages. Real-world problems, such this traffic survey in Brazil, generally are related with multicriteria decisions. Thus, motivated by this Brazilian problem, we propose the Multiobjective Support Unit Location Problem to Assist Roadside Traffic Survey with Multi-Stages to minimize the costs involved and the quantity of support units used on the whole survey. An exact multiobjective approach is used to find the Optimal Pareto for instances based on the Brazilian case and several analysis of the tradeoff between objectives are presented.

■ WB-44

Wednesday, 10:30-12:00 - Q115

Revenue Management in Production and Logistics

Stream: Revenue Management in Production and Logistics
Invited session
Chair: *Mehmet Barut*

1 - Leashed Reinforcement Learning for Dynamic Pricing in Container Logistics
Benoit Rottembourg, Niamh O'Connell, Pernille Hansen, Pimin Konstantin Kefaloukos

Dynamic pricing and revenue management are fundamental to the profitable operation of the modern airline, railway and cruise industries, yet these methods have not yet been deployed at scale in the container shipping industry. There are a number of barriers to the adoption of established methodologies, namely: -network scale and demand sparsity precludes accurate demand forecasting at the necessary granularity -the booking lead time in the container shipping industry is short, thus hindering the use of approaches which rely on forecastable outcomes -network capacity is in itself volatile, with carriers frequently omitting weekly sailings at short notice -customer cancellation rates can exceed 60% in some areas Despite these challenges, a number of leading container carriers are exploring the opportunities offered in this digital era, offering pseudo-dynamically priced products in the context of the spot market. In our presentation, we will demonstrate how dynamic pricing mechanisms can be automated within this highly volatile and complex market through the use of hybrid Reinforcement Learning mechanisms, with appropriate constraints and monitoring. Through our proposed technique, Leashed Reinforcement Learning, we aim to empower pricing managers to strategically guide the price engines toward declared objectives, requiring intervention only in outlier situations. Comparisons with rule based threshold policies and Markov Decision Processes will be provided.

2 - Integrating revenue management approaches into same-day-delivery operations
Vienna Klein, Claudius Steinhardt

Despite the significant growth of e-commerce and e-grocery services with increasing customer expectations regarding instant availability of goods, only few suppliers and logistics companies provide exhaustive same-day-delivery options in a successful way. Instead, most of these businesses struggle with cost-intensive process adaptions, low logistics margins, and inefficient routing operations. Existing means to overcome these limitations consider, for example, price diversification, alternative shipping strategies, anticipative routing, and 'click&collect'. The integration of revenue management approaches into same-day-delivery operations is rather uncommon so far. In this talk, we study dynamic pricing strategies with the intention to steer customer behaviour towards choosing delivery options that lead to better route efficiency and minimized delay penalties. We formulate the same-day-delivery pricing problem as Markov decision process. The dynamic pricing decisions are based not only on operational logistics cost, but also on losses in flexibility and potential future revenue. We study various approximate dynamic programming approaches that evaluate the problem online by comparing possible outcome states with valuations of neighbouring states that are learned offline.

3 - Capacity Rationing under Mixed Demand Patterns
Mehmet Barut

The proposed study investigates effectiveness of current Dynamic Capacity Allocation Procedure (DCAP)developed as rationing heuristics for capacitated order management in make-to-order environment, under mixed demand patterns. Current literature consists of stochastic model development under the assumption of same demand pattern over time across the product or market segments. This study releases this assumption and aims to provide statistical evidence whether DCAP performs significantly better than benchmark first-come-first-served policy under variety of mixed demand patterns. Thus, this study adds value by generalizing the effectiveness of DCAP as well as by investigating the desirability of its usage compared to optimum solution considering full knowledge. Its byproduct related to market share is also investigated.

■ WB-45

Wednesday, 10:30-12:00 - Q117

Urban Logistics

Stream: Green Logistics
Invited session
Chair: *Matthias Prandtstetter*
Chair: *Dmitry Krushinsky*

1 - The impact of the shared last-mile
Dmitry Krushinsky

A number of recent logistic concepts in the area of the last-mile delivery are centered around the idea of sharing (or outsourcing) the demand with other parties. Some examples of this include involving occasional drivers, taxis, public transport or other party operating in the area of interest. A number of studies focus on the performance of only one party: either the original demand 'owner', or the 'subcontractor'. Yet, it is not clear how sharing improves the overall performance of the global logistics system. Furthermore, the demands that are attractive (most profitable) for one party, may be also attractive for another party, leading to a kind of competition. By means of numerical experiments, we study the mentioned issues and provide general insights into the functioning of shared delivery systems.

2 - Exploring reservation and driver's flexibility benefits in carsharing systems
Mireia Roca-Riu, Monica Menendez

Carsharing systems are a growing trend in personal mobility. Different forms of carsharing, user's preferences, and environmental benefits estimation are some of the topics that have already been studied. Nevertheless, these systems need to be further improved to remain competitive. We focus here on a two way station based carsharing system and we explore the benefits of combining a reservation scheme and the driver's flexibility. The reservation scheme allows operators to plan the optimal number of vehicles offered at each station. Additionally, the driver's flexibility in the starting rental time can be exploited to optimize vehicle use. The reservation scheme is organized with an auction using the Vickrey-Clarke-Groves (VCG) mechanism for combinatorial auctions. The drivers are offered a reduced rental fare and they can flexibly bid for their preferred rental starting times. As a result, the drivers are assigned a rental period and a reservation fee. The reservation fee aims to compensate the reduction in the rental fares, and guarantees drivers' truthful participation. The scheme has been tested on instances inspired by the Mobility system in Zurich, Switzerland. The results demonstrate that by using the proposed scheme, operators can maintain the overall rental fees with reduced fleets. Sensitivity analysis shows that the potential benefits are higher in systems with shorter rentals, and that inhomogeneous drivers' flexibility also produces savings.

3 - Multi-period planning of an integrated item-sharing and crowdshipping platform
Moritz Behrend, Frank Meisel, Kjetil Fagerholt, Henrik Andersson

Item-sharing and crowdshipping are two concepts of the sharing economy. In item-sharing, members of a sharing community can temporarily rent items such as tools or leisure equipment from one another (peer-to-peer). In crowdshipping, private drivers offer to execute delivery jobs for other people on trips they would make anyway. It has been shown that the integration of the two concepts on a single platform has great potential in terms of profitability and service orientation. These findings were obtained in experiments with static information in which a decision making is required only for the next period. To allow for a more extensive planning and to account for the dynamics of such platforms, we present two new methodological extensions. First, we formulate a multi-period assignment problem that takes into account submitted requests that refer to future planning periods. Second, we propose a rolling horizon framework that allows to employ all developed static solution methods in a dynamic setting. Eventually, we derive managerial insights from numerical experiments in which we compare different response strategies of the platform, as a reaction to successively incoming announcements, and we re-evaluate the extent to which crowdshipping can support item exchanges.

4 - Tackling real world constraints in city centers vehicle routing problems
Maria Teresa Godinho

In this talk, we present an heuristic algorithm for a routing problem, designed to tackle with some challenging real world constraints. Specially hard to deal with, are the very tight time windows that arouse in collecting and/or delivering problems located in city centers, particularly in ancient and medieval towns, as in this case, where in some streets a car can barely pass and, not so rarely, an obstacle ill placed ruins the route planned before. Interesting enough, by tracking those occurrences it is possible to find patterns and explicitly expose these hidden constraints. In our approach, the algorithm receives and uses this information to recalculate the route allowing us to improve the performance of the system.

■ WB-46
Wednesday, 10:30-12:00 - L243

Fuzzy Optimization II

Stream: Fuzzy Optimization
Invited session
Chair: Beatriz Hernández-Jiménez

1 - Fuzzy Logic Modified Methodology Application in a Green Aircraft Technology
Ruxandra Botez

Green aircraft technologies are used to reduce fuel consumption, therefore flight time, to bring therefore important savings to the airlines, and benefits to the environment. One of these technologies is related to morphing wing design and experimental validation. In this abstract, the aim of the morphing wing system is to delay the flow transition position close to its trailing edge, and to reduce the drag. The drag reduction translates in fuel reduction. A new methodology consisting in a combination of a fuzzy logic proportional integral derivative and an on-off controller was designed for a morphing wing system. The shapes chosen of the inputs' membership fuzzy model functions were s-, π-, and z-functions; product fuzzy inference and the Sugeno center average defuzzifier were applied. The morphing wing was equipped with a flexible composite skin on its upper surface; smart material actuators and piezo-electric sensors were installed on the skin, and they were related using the combination of the controllers' methodology. The actuators have acted on the flexible skin using the new controller in order to obtain the optimized shape of the morphing wing for different flight cases. The pressure sensors were able to detect the flow transition position on the flexible skin upper surface. A closed loop controller was also designed and validated using experimental wind tunnel testing.

2 - Reduction of Optimization Problems with Fuzzy Relation Equation Constraints
Reinis Lama, Svetlana Asmuss

Fuzzy relation equations have been extensively investigated by a wide range of authors and have been established as an important tool in fuzzy modelling. There are many investigations related to optimization problems with fuzzy relation equation constraints with a specific composition, for example, max-min, max-product or addition-min composition. Solving algorithms have been proposed for these types of optimization problems, however in most cases the proposed algorithms can only be applied for the specified objective function, for example, linear or quadratic objective function.

This talk is devoted to optimization problems with fuzzy relation constraints where the constraints can have different compositions. The proposed method allows to reduce such problems to mathematical programming problems by adding integer variables. The method can be applied to an optimization problem with fuzzy relation equality constraints regardless of the objective function, including multi-objective optimization. Additionally, some properties of the reduced systems are examined. This research has been supported by the project LZP-2018/1-0338.

3 - Improved Optimality Conditions for Fuzzy Optimization Problems
Beatriz Hernández-Jiménez, Rafaela Osuna-Gómez, Antonio Beato-Moreno, Pedro L. Luque Calvo

We present an optimization problem where both the objective and constraints are given by fuzzy functions. In order to solve it, we first prove that these problems are equivalent to optimization problems where the constraints functions are non-fuzzy (real-valued) functions for each α in [0,1] and we introduce a new and wider stationary point concept that generalizes all existing concepts so far. This new stationary point concept is based on the gH-differentiability and has many computational advantages that we describe. It is well-known that obtain a useful differentiability notion for fuzzy functions is a difficult task without linearity. And we are in that case due to the fact that the fuzzy numbers (intervals) space is a nonlinear one. In this direction, the gH-derivative for fuzzy functions is a concept that is more general than Hukuhara and level-wise derivatives that are usually used in fuzzy optimization so far, in the sense that they can be applied to a wider number of fuzzy function classes than above concepts. With this new differentiability concept, we prove a necessary optimality condition for fuzzy optimization problems that is more operational and less restrictive that the few ones we can find in the literature so far.

■ WB-47
Wednesday, 10:30-12:00 - L247

Algorithms for Solving Complementarity Problems

Stream: Continuous and Black Box Optimization
Invited session
Chair: Florian Potra

1 - PC IPAs for sufficient LCPs and their computational performance
Tibor Illés

The goal of this talk is to summarize some of the current research trends, new results and open questions in the area of the linear complementarity problems and their applications.

The algebraic equivalent transformation (AET) of the system which defines the central path has been introduced by Darvay (2003) for linear programming problem resulting new search directions for interior point algorithms (IPA). Generalization of AET for some types of IPAs for sufficient linear complementarity problems (SU-LCP) can cause difficulties, especially for predictor-corrector (PC) ones. After overcoming these difficulties, we introduce new PC-IPAs for SU-LCPs. Moreover, we present a unified discussion of the effect of different AETs on proposing and analysing new IPAs for SU-LCPs.

These new PC IPAs from complexity analysis point of view possess similar properties like IPAs with the best know complexity, namely have polynomial iteration complexity in κ, the dimension n and the bit length L of the problem.

Computational performance of a variant of our, new PC IPA has been demonstrated on sufficient matrices generated by Illés and Morapitiye (2018) and on a well-known, triangular, P-matrix designed by Zs. Csizmadia (2011) with κ that is at least exponentially large in the dimension n of the problem.

Computational tests show better performance of our algorithm than it can be expected.

2 - A homogeneous model for monotone mixed horizontal linear complementarity problems

Florian Potra

We propose a homogeneous model for mixed horizontal linear complementarity problems. The proposed homogeneous model is always solvable and provides the solution of the original problem if it exists, or a certificate of infeasibility otherwise. Our formulation preserves the sparsity of the original formulation and does not reduce to the homogeneous model of the equivalent standard linear complementarity problem. We study the properties of the model and show that interior-point methods can be used efficiently for the numerical solutions of the homogeneous problem. Numerical experiments show convincingly that it is more efficient to use the proposed homogeneous model for the mixed horizontal linear complementarity problem than to use known homogeneous models for the equivalent standard linear complementarity problem.

3 - Adaptive full Newton-step infeasible interior-point method for sufficient horizontal LCP

Goran Lesaja, Florian Potra

An adaptive full Newton-step infeasible-interior-point method for solving sufficient horizontal linear complementarity problems is analyzed and sufficient conditions are given for the superlinear convergence of the sequence of iterates. The main feature of the method is that the parameter defining the full Newton-step is adaptively chosen at each iteration, in contrast with previous full-Newton step methods where this parameter is kept fixed at all iterations. We mention that no superlinear convergence results are known for the latter methods. The theoretical complexity of our method matches the best known results in the literature. In the first algorithm, we assume that an upper bound for the handicap of the problem is known. The second algorithm does not depend on the handicap of the problem, so that it can readily be applied to any horizontal linear complementarity problem.

4 - A full-Newton step infeasible interior-point method for weighted complementarity problems

Xiaoni Chi

The notion of a weighted complementarity problem (wCP), proposed by Potra, is to find a pair of vectors belonging to the intersection of a manifold and a cone such that the product of the vectors in a certain algebra equals a given weight vector. If the weight vector is zero, the wCP reduces to a complementarity problem. Several equilibrium problems in economics can be formulated as wCPs, such as the Fisher market equilibrium problem, the linear programming and weighted centering problem, and so on. Motivated by the recent work of Potra and Roos on interior-point algorithms, in this paper we present a full-Newton step infeasible interior-point method for the linear wCPs over the nonnegative orthant. The algorithm uses only full-Newton steps, so-called feasibility steps and centering steps. The iteration bound of the algorithm is as good as the best known polynomial complexity of infeasible interior-point algorithms for linear optimization.

■ WB-48

Wednesday, 10:30-12:00 - L248

Energy and Finance Models II

Stream: Mathematical Modelling
Invited session
Chair: *Hanaan Yaseen*

1 - Using homogeneous subsets in portfolio selection

Elmira Mynbayeva

Markowitz portfolio optimisation assumes we know the true values of the first two moments - means and variances. However, in practice, the true values are almost never known, and estimates are used instead. The portfolio optimisation model using estimates instead of true values tends to produce extreme weights and poor out-of-sample results. One of the possible explanations of this issue is estimation error or estimation risk. The Markowitz model is extremely sensitive to even insignificant deviations is estimates. We introduce a method which combines estimates that are not significantly different from each other into homogeneous subsets. After identifying groups of homogeneous means and homogeneous variances, we can apply an optimisation strategy. This can help to enhance diversification and improve the out-of-sample performance of the model. We also combine shrinkage estimators of means and covariance matrix with homogeneous subsets. We compare the results of different portfolio strategies in the sense of diversification and out-of-sample performance.

2 - Valuation monotonicity, fairness and stability in the assignment problem

Marina Nunez, Rene van den Brink, Francisco Robles

In two-sided assignment markets with transferable utility we first introduce weak monotonicity properties that are compatible with stability. We show that the sellers-optimal (respectively buyers-optimal) stable rules are the only stable rules that satisfy object-valuation antimonotonicity (respectively buyer-valuation monotonicity) which requires that if all buyers weakly decrease the valuation of a given object and this object remains assigned by the rule to the same buyer, then the payoff of this buyer does not decrease. Valuation fairness requires that changing the valuation of a buyer for the object of a seller leads to equal changes in the payoffs of this buyer and seller. This property is not compatible with stability. We show that weak valuation fairness, that requires equal changes only for buyers and sellers that are matched to each other before as well as after the change characterizes, among the set of stable rules, the fair division rules. Finally, adding a consistency axiom, the two optimal rules are characterized in the general domain of allocation rules for two-sided assignment markets with a variable population.

3 - Forecasting the Dividend Policy using Machine Learning Approaches

Hanaan Yaseen, Victor Dragota

Abstract: Dividend Policy is one of the most important decisions in corporate finance. There is a considerable practical and academic interest to determine which are the most relevant factors influencing the final decision of distributing dividends. In contrast, to the best of our knowledge, there is a limited amount of research done about the dividend prediction or dividend policy forecasting. For covering this important issue, we suggest an approach based on machine learning methods. In order to solve the optimization problems and for finding the most representative factors which influence the dividend decision, we use both Neural Networks (NN) and Chi-squared automatic detection classification tree models (CHAID). Using a large database of

11,248 companies from 70 countries, for the period of 2008-2014 we found the most relevant input factors which determine the output of distributing dividends or not. One interesting finding is that, on short list of factors, there are both companies' financial indicators and socio-cultural factors at country level. The best prediction models are similar for both developed and developing countries. The results indicate that the extrapolation of such models can be done for all companies considering also the country where it activates.

■ WB-49

Wednesday, 10:30-12:00 - L249

Dynamical Models in Sustainable Development I

Stream: Dynamical Models in Sustainable Development
Invited session
Chair: Christian Sölch

1 - Can Innovation in a segmented market ensure a triple bottom line solution in the context of transition to alternative fuel vehicles?
Wissam EL Hachem, Pietro De Giovanni

Innovation is a key aspect of modern competition, yet it has a known downside, the potential to cannibalize the existing products of a firm. However, disruptive technological change such as the emergence of the electric car, makes the risks of not innovating far greater. In this paper, we seek to highlight that under some circumstances, cannibalization and innovation are both needed to accommodate for changing customer values.

A firm's ability to improve quality and reduce costs, hence its pricing and quality decisions are dependent on current and past R&D investments (i.e. innovation). We will consider process and product innovation with spillovers and knowledge accumulation, within the context of transition to Alternative Fuel Vehicles, taking into consideration market segmentation with the objective of maximizing profits, minimizing emissions and satisfying the principle of distributive justice (DJ).

DJ in this context is defined as ensuring fair access to transportation based on three pillars: equity, equality and distribution on need.

There have been few attempts to study cannibalization and competition simultaneously in a segmented market, and no attempt as far as we know to consider with them innovation and/or the concept of DJ. This is a gap in the literature that this study aims to fill.

Our objective is to characterize situations wherein firms can profitably sustain a green product line while considering DJ, making for a triple bottom line solution.

2 - Dynamic Queue Reordering Model for Electric Vehicle Express Charge Stations
Nilgun Fescioglu-Unver, Emre Anıl Kakillioglu

Continuous growth in the number of electric vehicle users increases the need for express charging stations where the vehicles which need shorter service times can be charged after a shorter delay with respect to the others. Allocating a fixed number of charging units for express users does not guarantee a shorter wait time for these users. In addition fixed resource allocation decreases the overall utilization balance of the service units. In this study we propose using a dynamic queue reordering model for express charge stations. The model is based on the Highest Response Ratio Next (HRRN) method which is frequently used for computer CPU scheduling. HRRN method assigns a priority value to the vehicles which is a function of the required service time and the delay time the unit has already waited for. We test the model's effectiveness in a simulation environment and compare its performance with express charge station models which use fixed resource allocation and shortest processing time based queue reordering methods. Results show that using an HRRN based dynamic queue reordering model in express electric vehicle charge stations provides benefits to both station owners and users.

3 - Possible regulatory frameworks for enabling multiple use of storage devices by regulated and private market participants in smart grids
Christian Sölch, Veronika Grimm, Manuel Haußner, Roland Ismer, Gregor Zöttl

In many liberalized electricity markets, network operation and operation of generation and storage utilities are separated via unbundling regulations. In this paper we propose an equilibrium model that allows to analyse regulatory frameworks which enable the multiple use of storage devices by a regulated DSO and a private storage company and which are in line with applicable law. Our framework takes into account both storage investment and operation decided upon by private investors and network expansion and operation decided upon by a regulated DSO. In order to take into account the different objectives and decision variables of those different agents in our equilibrium framework, our approach exhibits a tri-level structure. We analyze regulations that allow the DSO to interfere in storage operation in case of network congestion. To provide economically and politically relevant statements based on our computation, we calibrate our framework for a case study of a city district with around 100 households and an installed photovoltaics capacity of 1 MW. Our results show that implementing the considered regulatory framework can give the right incentives for a system friendly storage operation and thus reduce the need for network expansion. We show that widening the freedom of the DSO to interfere in private storage operation more often can result in outcomes that are close to the system optimum but might also contrast with the unbundling regulations.

4 - Integrated markets and pollution taxes
Salvador Sandoval

This study develops a partial equilibrium model in integrated markets conditions into bilateral trade of a homogeneous good, in which two heterogeneous and monopolistic firms in their respective countries that generate pollutants compete under an oligopolistic scheme. In this way, governments must implement strategic environmental policies that guarantee a healthy environment, but at the same time consider the benefit of firms and consumers, as well as their own income through the collection of pollution taxes for firms. The results establish that, if the marginal cost to pollute is very high, the government must implement a high tax on pollution. On the other hand, if the marginal cost of polluting is not very significant, the government will apply a zero tax on the emission of pollutants.

■ WB-50

Wednesday, 10:30-12:00 - Mason Hayes & Curran

Understanding the practice of Problem Structuring Methods - I

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: Mike Yearworth

1 - Using Problem Structuring Methods to Design Innovative Business Models
Adrian Small, Suman Bhattacharya, David Wainwright

The rapid evolution of digital health technologies has given rise to new opportunities for telehealth and telecare (telehealthcare) solutions to address fundamental challenges. Research in digital health and health information technology has focused on government health strategy and policy issues at the macro level, or user acceptance amongst healthcare professionals and patients at the micro level. The emerging evidence base is highly skewed towards research and evaluation for telehealth and telemedicine solutions aimed at Clinical Professionals and patients with long term medical conditions, as opposed to assisted independent living in the home. Business models have increasingly gained the attention of academics and practitioners alike but their development is lagging within the health and social care sectors. Different conceptualizations of the business model construct are possibly due to the varying contexts and scopes under which business models are studied. Business models allow an exploration into how enterprises work allowing stakeholders to understand the 'customer' and what this 'customer', therefore, 'values'. There are, however, divergent views on what constitutes a 'classical' business and/or a service dominant logic model. Problem structuring methods are proposed as one way designers and creators of business and service models can attempt to understand and create new ways to address the problems of adoption of telehealthcare solutions.

2 - The Contribution of Problem Structuring Methods in OR
Harry Kogetsidis

Following their overall acceptance as a distinct field of Operational Research in the 1990s, Problem Structuring Methods (PSMs) have made an important contribution in dealing with messy, ill-structured situations, which are characterised by multiple actors with different perspectives and conflicting interests. Focusing on how to enable the different actors to work together, these participatory modelling approaches can play an important role in addressing problematic situations in organisations and society. There have been many cases of successful application of problem structuring methods and their use has been reported in OR journals and discussed in OR conferences.

The aim of this paper is to review how soft OR and problem structuring methods (PSMs) have been covered in the European Journal of Operational Research (EJOR) over the years and to identify current themes in terms of their application. The paper will look into whether PSMs are used alone or in combination with other methods or tools, as well as the broader paradigms that these modelling approaches are associated with. The paper will aim to address whether the field of soft OR / PSMs is generally seen as a legitimate part of OR and what its future might be.

3 - Problem structuring interventions in practice?
Mike Yearworth, Richard Ormerod, Leroy White

The derivation of generic constitutive rules for Problem Structuring Methods (PSMs) by Yearworth and White was motivated by the observation of everyday problem structuring in organisations. The existence of a 'problem structuring mentality' naturally provokes questions about appropriate underlying theory, especially when this might provide the means for connecting research into OR practice with wider debates in the management literature. There is already a nexus around the practice of problem structuring and theorising about it and, as discussed by Ormerod, social practice theory offers a way forward. By moving on from debates about the evaluation of PSM performance we can start to address how the workshop nature of PSM engagements provides a unique insight into the particular place and particular time of management decision making when dealing with messy problems. Here we set out some provocative research questions to define an agenda and we discuss their implications for OR practice.

■ WB-51

Wednesday, 10:30-12:00 - William Fry

Optimal Control Theory

Stream: Optimal Control Theory and Applications
Invited session
Chair: Vladimir Veliov

1 - Optimal control of piecewise-smooth systems and sliding dynamics
Anton Bondarev

The field of piecewise-smooth dynamical systems is actively studied in recent years. Still from the point of view of optimal control, not much have been done to formulate and solve associated optimization problems. In this paper, I study the simplest possible linear-quadratic control problem with additional bilinear terms in objective functionals, which has a single switching manifold. Such hybrid control problems are scarce in the literature and the rigorous formulation of the Maximum Principle is still lacking. At the same time such systems have multiple economic and management applications, ranging from advertisement models to environmental systems and R&D competition. Thus, it is important to understand the optimal dynamics and how it differs from uncontrolled one.

I first study the global geometry of the (optimized) flow and prove that even if co-state variables may jump at the switching manifold, these jumps are ruled out by the optimality principle and the resulting canonical system is a continuous one.

Next, I provide conditions on the state-space geometry for the optimal trajectory to lead to the so-called pseudoequilibrium of the sliding flow at the boundary between regimes of dynamics.

At last, I demonstrate that the existence of this optimal solution is topologically invariant to the number of controls, but not to the number of states and crucially depends on the degree of asymmetry across regimes of the problem.

2 - OPTCON_Dual: an active learning optimization algorithm for nonlinear quadratic problems
Viktoria Blueschke-Nikolaeva, Dmitri Blueschke, Reinhard Neck

In this paper, we develop an algorithm (called OPTCON_Dual) for the optimal control of nonlinear stochastic dynamic economic systems according to a quadratic objective function. The OPTCON Dual algorithm allows to take into account the dual nature of optimal controls: controls are applied to not only guide the system along its desired path but also aim at reducing uncertainty, i.e. learn about the system model in an experimental way. To derive an optimal solution under active learning strategy we apply the grid search method and split the total objective function into a deterministic, a cautionary and a probing term. We present the algorithm and report about experiences of applying it to a small econometric model as well as comparison with results from the earlier versions of the OPTCON algorithm (with open-loop strategy and passive learning strategy).

3 - Weak solutions for a class of Hamilton-Jacobi-Bellman (HJB) equations arising in stochastic optimal control
Teresa Scarinci

The value function or cost-to-go function of an optimal control problem might be characterized as the solution of a partial differential equation (called the HJB equation.) Since the value function cannot be expected to be smooth and global classical solutions of the HJB equation do not exist in general, one needs to relax the concept of solution. This topic is well-developed and investigated in many papers, starting from the pioneering work by Crandall, Ishii, Lions, "User's guide to viscosity solutions of second order partial differential equations". The main interest comes from the fact that the theory of HJB equations can provide an efficient tool to compute or calculate in a feedback formulation the optimal control of the problem. In this talk, we will introduce a class of stochastic optimal control problems where the dynamic is constrained by control constraints and endpoint state constraints. Indeed, in this case the value function cannot be expected to be more than lower semicontinuous and also the theory of viscosity solutions cannot be directly applied. A suitable relaxation of weak solution for the corresponding HJB equation will be discussed. This task brings further difficulties; indeed, results of existence and uniqueness of solutions might not be trivial to be investigated. Moreover, stochastic verification theorems must be provided; these are key tools in utilizing the dynamic programming technique to compute the optimal control.

4 - Optimality and approximations in affine control problems
Vladimir Veliov

Optimal control problems that are affine with respect to the control arise in many applications, especially in electrotechnics and electronics. The numerical analysis of such problems is challenging due to the typical discontinuity of the optimal controls. The talk will present new results concerning the theoretical background for various approximation approaches. The results will be demonstrated on several particular numerical methods. The talk will be based on joint works with N. Osmolovski, J. Preininger, M. Quincampoix, and T. Scarinci.

Wednesday, 12:30-14:00

■ WC-01

Wednesday, 12:30-14:00 - O'Reilly Hall

Ivana Ljubic

Stream: Tutorials
Tutorial session
Chair: Markus Leitner

1 - From Game Theory to Graph Theory: A Bilevel Journey
Ivana Ljubic

In bilevel optimization there are two decision makers, commonly denoted as the leader and the follower, and decisions are made in a hierarchical fashion: the leader makes the first move, and then the follower reacts optimally to the leader's action. It is assumed that the leader can anticipate the decisions of the follower, hence an optimal solution for the leader can be obtained by solving a nested optimization problem that takes into account the follower's best response.

In this talk we focus on new branch-and-cut (B&C) algorithms for dealing with mixed-integer bilevel linear programs (MIBLPs). We first address a general case in which intersection cuts are used to cut off infeasible solutions. We then focus on a subfamily of MIBLPs in which the leader and the follower share a set of items, and the leader can select some of the items to inhibit their usage by the follower. Interdiction Problems, Blocker Problems, Most-Vital Node/Edge Detection Problems are some examples of optimization problems that satisfy the later condition. We discuss implementation of a generic, efficient B&C scheme that relies on the separation of "interdiction-cuts".

These new B&C algorithms consistently outperform (often by a large margin) alternative state-of-the-art methods from the literature, including methods that exploit problem specific information for special instance classes.

■ WC-03

Wednesday, 12:30-14:00 - Q106

Tutorial: let the data do the talking

Stream: Practice of OR (Making an Impact)
Tutorial session
Chair: Jasper Lodder

1 - Tutorial: let the data do the talking
Jasper Lodder

As Tom Davenport (known for proclaiming Data Science to be the most sexy job on the planet in 2012) says in https://www2.deloitte.com/insights/us/en/topics/analytics/data-driven-storytelling.html "Most people can't understand the details of analytics, but they do want evidence of analysis and data. Stories that incorporate data and analytics are more convincing than those based on anecdotes or personal experience. Perhaps the most compelling stories of all are those that combine data and analytics, and a point of view or example that involves real people and organizations." Jasper Lodder will take us through the available technologies and methodologies for effective analytics storytelling, all the way from the first contact with messy data to taking decisions based on optimization models.

■ WC-05

Wednesday, 12:30-14:00 - A003

Sustainability in Value Chains

Stream: Sustainable Supply Chains
Invited session
Chair: Martin Behnke

1 - An overview of Modelling and Simulation for Sustainable Food Supply Chains

Lampros Stergioulas, Masoud Fakhimi

Food supply chains are increasingly dealing with continued complexities of stakeholders' demands for Sustainable Development. Over the last two decades, research in sustainable supply chains has made significant contribution towards the understanding and implementation of Triple Bottom Line (TBL) in agrifood supply chains. Modelling and Simulation (M&S) methods are widely used in management science, and enable decision makers to study and evaluate strategies for effective management of complex systems. Thus, M&S studies have been extensively applied in supply chains to gain insights into existing or proposed systems of interest. Our literature review indicates that the number of empirical research and models being developed for implementing and managing the TBL of sustainability in food supply chains are still scarce and this research field is still in its infancy. In existing studies, the focus of models is mainly on the productivity of systems rather than on social and environmental aspects of supply chains. This paper explores research on M&S for food sustainable supply chains, aiming to investigate the challenges in developing models for sustainability analysis. The presented research takes the informed view that the discipline of Sustainable Supply Chains will benefit from further exploration of M&S in the context of modelling for sustainability. The outcomes of this research provide insights toward future research directions and needs in this area.

2 - Is it more expensive the external supply of raw materials when a green planning is done? A case study.

Juan Bermeo, Victoria Rodriguez, María Álvarez

Land freight transport substantially contributes to greenhouse gas emissions through fuel use. The aim of this study is to assess the environmental impact regard to economic impact of supply policies in the transportation network, such as the number of stops that a truck supplying raw materials can make on route. We consider the case of well-known European automobile company. Mixed-integer programming is proposed to solve small size instances, and a tabu search metaheuristic algorithm is applied to the solution of large size instances. This paper is from benefit to academics and managers by providing a real comparison when a green planning is done and when not in automobile industry.

3 - Nested model for distributed decision-making in global value chains

Adel Guitouni

Decision-making within clusters of self-organized and vertically related but independent firms to create value continues to function despite their lack of awareness of each other's goals, capacity, labour, knowledge and technology. Little theory exists in either the decision sciences, the management, economics or engineering literature to explain how distributed decision-making and information exchange occur within co-production networks (CPNs) such as global value chains (GVCs). Prior research shows that decision-making within complex economic systems must account for how value emerges, is perceived and aggregated within these CPNs. In this contribution, we develop a nested decision-making model with at least four levels. First, the value must account for how value is created and measured despite its amorphous qualities, and the lack of consensus on what constitutes value. Second, value aggregation is multi-dimensional and, for our purpose, we consider the triple-bottom-line approach, which aggregates three value dimensions, i.e. economic, social, and environmental. Third, the question of whose perspective defines which criteria are pursued must be understood. The fourth level relates to how the value changes and accumulates over time and space. We address value measurement, the incommensurability related to multiple criteria aggregation, the difficulties inherent to stakeholder inclusion, and the problems of spatial-temporal accumulation of value along the supply chain.

4 - Vehicle routing with emission allocation preferences considering EN 16258

Martin Behnke, Thomas Kirschstein, Christian Bierwirth

As freight transportation is responsible for about 24 % of the CO_2e emission in Europe the transport industry is required to substantially reduce greenhouse gas emission. To declare GHG emission by transport services the European Commission proposed an emission reporting standard EN 16258. With this paper we conceptualize an approach which enables logistic service providers to determine vehicle tours and to allocate cost and emission to the shippers according to their preferences and EN 16258. The norm prescribes possible allocation parameters: transport performance, egalitarian, distance- or load-based allocation or even linear combinations of these. Selecting an allocation measure establishes an additional instrument for the service provider to meet shipper's preferences. Incorporating these aspects requires to model the emission-relevant decisions yielding a heterogeneous VRP with emission and cost allocation. We will present approaches to meet shipper preferences for emissions and costs and discuss their pros and cons. Particularly, one option is to formulate hard upper bounds on the allocated emissions for each shipper and seek for the cost-minimal solution. A second possibility is to consider soft preferences and regard these for the routing and allocation problem. Another approach is to decompose the planning problem into routing and separate allocation whereby various objectives can be pursued and the allocation model allocates costs and emissions.

■ WC-06

Wednesday, 12:30-14:00 - A004

Efficient Approaches for Solving Expansion Planning and Network Flow Problems

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Manuel Ruppert
Chair: Valentin Bertsch

1 - Improving solution times of Capacity Expansion Energy System Models using aggregated problem solution as warm start

Stefanie Buchholz, Mette Gamst, David Pisinger

Energy System Models are complex MIPs that frequently need substantial CPU time to be solved. We study Capacity Expansion Models which are used for finding an optimal mix of technologies to secure stability in future energy systems. The need of model detail for this purpose tends to increase. Firstly, due to the many possible alternatives to fossil fuel, the solution space grows. Secondly, a detailed modelling including e.g. unit commitment makes the models NP-hard to solve. Consequently, simplification methods are needed. Promising results have been reported using aggregation, where the reduced models capture most of the needed investments while being much faster to solve. However, the solutions typically are sub-optimal, and a too aggressive aggregation may lead to infeasible solutions for the original problem. We analyze the potential of achieving optimal solutions using less computational time. By warm-starting the solution process of the original problem using solutions of aggregated problems, we help the MIP solver in finding good search directions. Moreover, we suggest to exploit the high quality of aggregated solutions by reducing the solution space according to the aggregated investment strategy to reduce solution times even further. Results show that the gains of using warm starts depend on both warm starting solution and problem instance. Still, using the reduction span on investments, solution time reductions for most warm starts are seen with reductions up to 75%

2 - Generation and transmission network expansion planning in power systems with a high share of renewable energies considering multiple weather years
Viktor Slednev

With an increasing integration of fluctuating renewable generation into power grids, the necessity to consider grid restrictions for the planning and secure operation of the power system is gaining in importance. In this context, the challenge to ensure the security of supply in the generation expansion planning (GEP) and transmission network expansion planning (TNEP) increases. For an adequate decision support, models are needed which are able to provide a secure TNEP and GEP considering the impact of varying weather conditions on the renewable generation in combination with central and decentral flexibilities. Based on the coupling of multiple models we present an approach for a secure TNEP and GEP considering the non-availability of generators due to stochastic outages or varying resource availability in multiple weather years. Neglecting load flow restrictions in the first step we run a highly resolved allocation planning of renewables, a Monte-Carlo based two-step optimization of national capacity requirements and an hourly resolved multi period GEP on the European scale. In the next step grid restrictions based on the DC-approach for Germany and its neighbouring countries are included and the TNEP and GEP (with fixed capacities) is conducted. In order to handle the complexity of the problems, different decomposition techniques, including the Alternating Direction of Multipliers Method (ADMM) and Benders Decomposition, are applied.

3 - Computationally Efficient N-1 Secure Load Flow Representation
Richard Weinhold, Robert Mieth

Relative to the ongoing changes of the electricity market power transmission and distribution infrastructure remains virtually static. Grid utilization needs to be highly efficient to accommodate physical power delivery at all times while simultaneously comply with strong security requirements. Network constrained optimal dispatch decisions are not only restricted by the thermal limits of the power lines, but also by complex security requirements such as the N-1-criterion. For real-world networks the N-1 security constrained optimal power flow (SCOPF) leads to a prohibitive increase in complexity even for linearized (DC) power flow. However, traditional approximation, e.g. based on fixed error margins, is not suitable for analysis of market-strategies closely related to the physical state of the line, such as optimal redispatch and flow based market coupling. This paper presents a methodology for a true N-1 representation by reducing the grid matrix to the minimal set of constraining lines. This allows a fast SCOPF solution that can be implemented in multi-period economic analyses. The matrix reduction is performed by an iterative algorithm with performance guarantees based on both general algebraic theory and exploiting peculiarities of the optimal dispatch problem. The method is showcased on the classic IEE 118-bus test system as well as a full-scale real-world system. Implementation relies on open-source systems and data and will be published supplementary to the paper.

■ WC-07

Wednesday, 12:30-14:00 - A007

Multi-Criteria DSS

Stream: Decision Support Systems
Invited session
Chair: *Pascale Zaraté*
Chair: *Adiel Teixeira de Almeida*

1 - An interactive methodological framework for the Analysis and Improvement of Robustness in Multicriteria Disaggregation - Aggregation methods
Athanasios Spyridakos, Nikos Tsotsolas, Isaak Vryzidis

UTA methods concludes to the assessment of additive value preference models based on Decision Makers (DMs) global preferences expressed by the rank ordering of a limited set of alternative actions evaluated into a consistent family of criteria. The assessment of the preference model through Linear Programming (LP) techniques is characterized, in many cases, by low robustness due to the existence of infinite solutions of the LP, bordered into a multi dimensional hyper polyhedron. Post optimality techniques are employed in order to identify the borders of the hyper polyhedron and finally a representative solution (usually the barycenter of the hyperpolyhedron) is selected. This research work presents a methodological frame for the analysis of the robustness of the estimated preference models and a set of a posteriori interactive feedbacks for the improvement of the robustness. The robustness analysis of the preference models is achieved by the investigation of cutting multi dimensional hyper planes of the hyper polyhedron and the utilization of a set of indices such as the Average Stability Index (ASI), the Priorities Reversal Index (PRI) and the entropy. The outcome of the robustness analysis lead to the elicitation of additional preference information by the DM through focused dialogues and visual techniques in order to enrich the LP and finally to improve the robustness. Also, the RAVI software system which embeds the above methodological approach is presented.

2 - Multicriteria decisions for investment in innovative upper-middle income countries GII 2016
Carlos Francisco Simoes Gomes, Marcela do Carmo Silva, Helder Gomes Costa

Observing how to invest in upper-middle income countries via an innovation perspective following Global Innovation Index (GII) by Multicriteria Decision Aid (MCDA) approach, once MCDA was designed to support subjective decisions. Pearson's correlation was the milestone for understanding innovation indicators at upper-middle income countries profiles. In a MCDA first step, the Analytical Hierarchy Process (AHP) was applied to obtain the criteria weight; whose judgements or evaluations inputted in AHP were collected from a sample composed by experts in GII. After getting the criteria weights composes GII, Borda and PROMÉTHÉE (Preference Ranking Organization Method for Enrichment Evaluations) methods were applied to obtain an MCDA-based GII. The inputs for this second step were: the weights come from AHP output, and, the countries performance came from GII data. As a result, it was found out the upper-middle countries' rank to invest and groups with countries acting like "hubs" or "bridges" for economic sectors in near countries. The results also show multicriteria decision aid as a supportive decision tool for decision-makers consider several perspectives of investment from criteria and alternatives analysis.

3 - Multiple Criteria Performance Modelling and Decision Analysis of Multi-vector Decentralised Energy Systems
Ting Wu

Renewable energy is essential for the world economy and the current and future generations' welfare, and it contributes in a balanced way to attain the general goal of energy security and environmental protection. Sustainable energy development should take into account not only energy saving and efficiency, but also transforming centralized energy systems to clean and decentralized energy (DE) systems. This research aims to develop a multiple criteria performance modelling and decision analysis framework for multi-vector decentralised energy systems. The evidential reasoning (ER) approach is employed to represent and aggregate various performance factors in either quantitative or qualitative nature under uncertainty. A case study is introduced to illustrate the feasibility decision analysis of constructing different multi-vector decentralized renewable energy systems in an industrial park. Four micro-grid configurations are identified as alternatives and then appraised by comparison against a series of criteria, and a multi-criteria decision model is then developed to rank those options. Sensitivity analysis is also conducted to analyse the reliability of the decision making. It is believed that different stakeholders, including policy makers, energy suppliers, consumers, network owners and investors, can potentially benefit from the informed and insightful decision making process with the support of the proposed performance modelling and decision analysis framework.

4 - A DSS for Preference Elicitation in Multicriteria Decision Aid with FITradeoff Method
Adiel Teixeira de Almeida, Eduarda Frej, Lucia Roselli, Jonatas Almeida

This paper discusses the use a DSS (Decision Support System) with the FITradeoff method for Multicriteria Decision Aid. The method uses partial information obtained from DMs with tradeoff questions for criteria aggregation by an additive model in MAVT scope. For choice of the best alternative the FITradeoff explores potential optimal alternatives. For ranking of alternatives, the method searches for dominance relations between those alternatives. In both problematics the results are obtained from different sets of linear programming models. The Preference Modeling process has been improved by using graphical visualization. With neuroscience experiments it has been possible to improve the design of the DSS and to produce insights for the analyst when interacting with decision makers (DMs). A decision support system, available at www.fitradeoff.org, has been applied in many decision problems, so the applicability of the DSS is illustrated with some of those problems.

■ WC-08

Wednesday, 12:30-14:00 - A008

Optimization under uncertainty - theory, applications and algorithms

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Milos Kopa*

1 - Independent sets and vertex covers considered within the context of robust optimization
Ana Klobučar, Robert Manger

This paper is concerned with robust variants of the maximum weighted independent set problem and, respectively, the minimum weighted vertex cover problem. Both problems are posed in a graph whose vertices are given weights. Uncertainty in vertex weights is expressed through a finite collection of explicitly given scenarios. The paper explores whether the complement of a robustly optimal independent set must be a robustly optimal vertex cover, and vice-versa (as it is true for conventional optima). It turns out that the answer to this question is not straightforward. More precisely, the answer depends on the chosen criterion of robustness.

2 - Robust optimization model for aggregate production planning under implementation errors
Byung Do Chung, Jaeyeon Jang

Aggregate production planning determines work force level and production quantity to match supply and demand while maintaining the effectiveness and responsiveness of manufacturing and supply chain systems. In this research, implementation errors related to hiring and layoff decisions are considered to be uncertain. Aggregate planning problems has many equality constraints and the problem becomes more complex when integer decision variables are considered as uncertain. Therefore, a traditional robust optimization approach might provide a conservative solution. To overcome this issue, we propose a bi-level particle swarm optimization model to determine robust aggregate plan that is always feasible and robust to unexpected implementation error. With numerical experiments, we showed that that the proposed approach outperforms a deterministic model and a conventional robust counterpart and in terms of the average cost and the worst case cost. The proposed model is also better than a conventional robust counterpart when the realized value is larger than the expected uncertainty.

3 - Comparing techniques for modelling uncertainty in a maritime inventory routing problem
Filipe Rodrigues, Agostinho Agra, Marielle Christiansen, Lars Magnus Hvattum, Cristina Requejo

Uncertainty is inherent in many planning situations, namely in maritime transportation, where weather conditions and port occupancy are typically characterized by high levels of uncertainty. We consider a maritime inventory routing problem where travel times are uncertain. Delays in the travel times may result in inventory surplus or shortages at the storages located at ports. Several techniques to deal with uncertainty, namely deterministic models with inventory buffers; robust optimization; stochastic programming and models incorporating conditional value-at-risk measures, are considered. The different techniques are tested for their ability to deal with uncertain travel times for a single product maritime inventory routing problem with constant production and consumption rates, a fleet of heterogeneous vessels and multiple ports. We assume two-stages of decisions, where the routing, the visit order of the ports and the quantities to load/unload are first-stage decisions, while the visit time and the inventory levels at ports are second-stage decisions. Several solution approaches resulting from the proposed techniques are considered. A computational comparison of the resulting solution approaches is performed to compare the routing costs, the amount of inventory bounds deviation, the total quantities loaded and unloaded, and the running times. This computational experiment is reported for a set of maritime instances having up to six ports and five ships.

■ WC-09

Wednesday, 12:30-14:00 - B006

Performance Measurement V

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Veronika Hedija*
Chair: *Martina Kuncova*

1 - Fuzzy cross efficiency in data envelopment analysis
Shiang-Tai Liu

Data envelopment analysis (DEA) is a methodology for measuring the relative efficiencies in a group of decision making units (DMUs). However, the evaluation may leads to the situation that many DMUs are evaluated as efficient, and the efficient units cannot be further discriminated. Cross efficiency is a concept for solving the problem of incomparability among the efficiencies of a set of DMUs calculated from different weights in DEA, and is helpful for ranking. In the real world, observations are usually difficult to measure precisely. One way to manipulate imprecise data directly is to represent the uncertain values by fuzzy numbers. Under the framework of DEA, different fuzzy DEA approaches for measuring efficiency with fuzzy data have been proposed. However, similar to crisp DEA models, it is possible that DMUs are classified as efficient units even although the input and output data are fuzzy numbers, and this leads to the task of ranking more difficult. In this case, the fuzzy cross-efficiency evaluation can be used as a tool to rank efficient units in fuzzy environments. This study develops a novel method to calculate the fuzzy cross-efficiency scores for DMUs with fuzzy data. A pair of two-level mathematical programs is developed to calculate the fuzzy cross-efficiency. The illustrated examples show that the fuzzy cross-efficiency evaluation method proposed in this paper has the discriminating power in ranking DMUs when observations are fuzzy numbers.

2 - A stochastic nonparametric approach for estimating Malmquist-type indices
Yu Zhao, Hiroshi Morita

The Malmquist index constructed from distance functions can be utilized as a useful tool for measuring productivity growth. In this study, we assume the presence of random noise in the real-world data and estimate the Malmquist-type index based on the use of nonparametric methods. In particular, we apply the estimator of stochastic nonparametric directional distance functions (Kuosmanen and Johnson, 2017) and further extend it from a cross-sectional structure to the case of a panel-data structure. A major feature of our approach is that it measures productivity change over time and meanwhile captures both inefficiency and noise in a nonparametric multiple-input multiple-output setting. We address how to deal with the estimation and decomposition of the presented Malmquist-type index. An illustrative empirical application will also be discussed.

3 - Use of dual-role variable according to size of DMU
Lucie Chytilová

Traditional Data Envelopment Analysis (DEA) assumed that decision making units have only output and output decision variables and there are no variables which can play both roles at the same time. Nowadays, there exit some models which are using so called dual role decision variable. The paper analyses a new structure of DEA model where the role of the dual role is set according the need (the size) of the decision making unit (DMU). In the end of the paper the application is illustrated.

4 - Relationship between Economic Efficiency and Profitability of the Pig Breeding
Veronika Hedija, Martina Kuncova, Roman Fiala

The sector of the raising of swine belongs to the traditional and very important sector of agriculture in the Czech Republic. The pork is very popular among Czechs, the consumption of pig meat was about 40 kg per capita which represented approximately 50 percent of total consumption of meat in 2017 in the Czech Republic. The external trade of the Czech Republic with live pigs reaches a surplus of the trade and the Czech Republic belongs to a net exporter of live pigs. The following study is devoted to the pig breeding industry. The study aims to examine the link between economic efficiency and profitability of firms belonging to the raising of swine sector in the Czech Republic. Data was exported from the database Albertina CZ Gold Edition and the data for subsector of raising of swine according to statistical classification of economic activity CZ-NACE 01.460 for the year 2017 was used. To evaluate the economic efficiency, the data envelopment analysis (DEA) models were applied, specifically the CCR (Charnes, Cooper and Rhodes) and BCC (Banker, Charnes and Cooper) models based on 3 inputs and 1 output. Return on assets (ROA) and return on sales (ROS) were used as the measurement of profitability. To assess the relationship between economic efficiency and profitability the Pearson and Spearman correlation coefficients were used.

■ WC-10

Wednesday, 12:30-14:00 - H0.12

Recent Progress in Randomized Derivative-free Optimization

Stream: Derivative-free Optimization
Invited session
Chair: *Anne Auger*
Chair: *Cheikh Toure*

1 - Variance Reduced Methods in Derivative Free Optimization
Sebastian Stich

Derivative free methods do in general not scale well when the number of variables increases. Concretely, the complexity estimates typically depend linearly on the dimension of search space. Recent advances have shown that variance reduction techniques can alleviate this dependency, having complexity that only scales sublinearly in the dimension. In this talk we will review some of these methods, discuss recent progress and show connections to mechanisms that been already successfully been deployed in derivative free search heuristics.

2 - Recent Advances in Large-Scale Derivative Free Optimization
Tobias Glasmachers

The maybe most interesting and at the same time highly relevant recent algorithmic breakthrough in continuous derivative free optimization is the development of powerful evolution strategies for large-scale problems. They are capable of optimizing up to d=105 continuous variables efficiently. The methods of primary interest are closely connected to the covariance matrix adaptation evolution strategy (CMA-ES), the defacto standard algorithm for continuous derivative free (direct) search. Due to its most powerful feature - online learning of the full covariance matrix - CMA-ES scales poorly to high-dimensional problems due to its quadratic (d2) algorithm-internal sample complexity. The classic "solution" to this problem is to drop covariance matrix adaptation, which can be extremely detrimental to optimization performance. Instead, modern methods like LM-CMA-ES (inspired by L-BFGS), DX-NES, VD-CMA-ES, and LM-MA-ES model only a part of the covariance information. This way they manage to marry learning of the most relevant parts of the covariance matrix with a tractable algorithm internal complexity. They feature a variety of different representations of the covariance matrix, and they have spawned the development of novel algorithmic components that may be of value in their own right. This talk gives an overview of recent techniques, presents results on widely used benchmark problems, and also investigates principal limits of direct search in high dimensions.

3 - Penalized Hypervolume Improvement for Multiobjective Problems: COMO-CMA-ES and the Sofomore framework
Cheikh Toure

We present a novel framework to build a multiobjective algorithm from single-objective ones. Denoting n the search space dimension, this framework approaches the p*n-dimensional problem of finding p solutions maximizing an indicator by dynamic subspace optimization. Each single-objective algorithm optimizes in turn a changing fitness defined as the indicator function given p-1 fixed solutions. Dominated solutions are penalized by the distance to the empirical Pareto front defined by those p-1 solutions. We instantiate the framework with the hypervolume as indicator and CMA-ES as single-objective algorithm. The new algorithm, COMO-CMA-ES is empirically shown to converge linearly on bi-convex-quadratic problems and is compared to MO-CMA-ES, NSGA-II and SMS-EMOA. We benchmark COMO-CMA-ES on COCO to measure its performance over all non dominated points found during a run.

■ WC-11

Wednesday, 12:30-14:00 - H1.12

Applications of Mixed-Integer Nonlinear Programming

Stream: Mixed-Integer Nonlinear Programming
Invited session
Chair: *Dennis Kreber*

1 - Optimal sampling under cardinality constraints
Ulf Friedrich

We study a class of non-linear integer optimization problems that are motivated by statistical sampling methods. The cardinality of the sample is fixed and the objective is to minimize the variance of the drawn sample. In its most general form, this problem is formulated with a convex objective function and a single cardinality constraint. However, in order to improve the quality of the model in practice, it is beneficial to include information of subordinate levels into the formulation, e.g., available data for the statistical population in certain regions. This defines a stratified problem with constraints on several levels. We analyze the structure of this problem and show how it can be solved efficiently in many cases. In addition, minimizing the variances of multiple statistical variables simultaneously extends the problem to a multi-objective optimization problem. We discuss the scalarization of the multivariate problem and run numerical tests of the proposed combinatorial algorithms using the open household data set AMELIA.

2 - Novel cuts for the subset selection regression
Dennis Kreber

We consider a least squares problem with a cardinality constraint limiting the number of nonzero coefficients. This mixed-integer nonlinear program is called the best subset selection regression and is used to compute a linear predictive model from given data. The cardinality constraint prevents the model from overfitting, since only relevant variables are intended to be selected, and hence the procedure yields excellent predictions. Bertsimas et al. (Best subset selection via a modern optimization lens, The Annals of Statistics, 2016) highlighted the importance of this problem and were able to solve large-sized instances in a viable time frame by using elaborated MIP techniques. However, finding a globally optimal solution still requires high computational effort.

We present novel cuts for the subset selection regression problem, which reduce the run time considerably. The cuts, which are derived from a matrix fractional program, are shown to be closely related to a perspective formulation. As the perspective formulation can significantly tighten the relaxation of a MINLP, the generated cuts show the same beneficial effect.

We verify the insights by a computational study, where we compare state-of-the-art approaches to formulations with the cutting planes. We observe that the cuts are highly effective in closing the MIP gap and that formulations utilizing the cuts are highly competitive.

3 - A Mathematical Programming approach for conflict avoidance in air traffic management
Sonia Cafieri, Andrew Conn, Marcel Mongeau

We propose a Mathematical Programming approach for one of the most challenging problems arising in Air Traffic Management, that is the one of ensuring separation between all pairs of aircraft at all time during their cruise flights. Conflict avoidance is addressed by adjusting both aircraft speeds and aircraft heading angles simultaneously. The ensuing model has nonlinearities and nonconvexities arising in the separation constraints and the integer variables modelling the inherent combinatorics of the problem. Our approach relies on mixed-integer nonlinear programming, which benefits of some tailored reformulations, linearization of nonlinear angle-related terms, and valid linear inequalities. Numerical results validate the proposed approach showing that it is able to find competitive solutions.

■ WC-12

Wednesday, 12:30-14:00 - H1.51

Applications in Logistics and Health Care

Stream: Combinatorial Optimization I
Invited session
Chair: Valentina Cacchiani

1 - Coalition structure and cost allocation problems in collaborative logistics
Martin Kidd

In collaborative logistics the formation of coalitions often allows agents to operate more efficiently than they can do on their own. On the other hand, there exist difficulties in managing large coalitions, and so the grand coalition is not necessarily the best solution. The question then arises as to which coalitions should form, which requires solving a set partitioning problem. Each potential coalition has a cost associated with it that is calculated by solving an optimization problem involving the members of the coalition. Depending on the coalitions that form, these costs need to be allocated to players in a stable and fair way with the help of concepts from cooperative game theory. In this talk we compare some exact and heuristic approaches to different variants of this problem.

2 - Mathematical models and exact algorithms for the Hospitals / Residents problem with Couples and Ties
Maxence Delorme, Sergio García Quiles, Jacek Gondzio, Jörg Kalcsics, David Manlove, William Pettersson

In the Hospitals / Residents problem with Ties (HRT), we are given a set of residents (junior Doctors) that have to be assigned to a set of hospitals based on their preferences over one another. The objective is to find a matching of maximum cardinality that ensures stability, i.e., a matching where no pair resident/hospital prefers to be matched together more than the hospital/resident they are currently assigned to. It is well known that the problem can be solved in polynomial time when the preferences are strictly ordered, and that it becomes NP-hard when ties are allowed in the preference lists. However, effective ILP models were proposed recently and successfully solved instances of reasonable size.

In this talk, we are interested in the extension of HRT in which residents are allowed to make their applications in couples. We start by reviewing the extensions of stability constraints that were proposed in the literature for couples and we outline the main differences and resemblances that exists among them. We then introduce new integer linear programming (ILP) models for each stability constraints and propose some improvements to reduce their running times. We finally show how the different models behave both on real-world and randomly generated instances.

3 - Analyzing nurse scheduling scenarios for a healthcare blended call center using discrete event simulations
Viviane Gascon, Omar Jaibi, Chantal Baril

Call centers have been studied mainly in the context of companies wishing to provide efficient customer services. Within this research, we consider a call center providing a free and confidential telephone consultation service for nonurgent health problems. This call center operates 24 hours a day, all year round. It is considered a blend center allowing for inbound calls as well as for outbound calls when required. The call center managers want to minimize users waiting time while maintaining an adequate nurse utilization rate. Even though assessing the number of inbound calls is a difficult forecasting problem, data analysis showed some patterns depending on the period of the day, of the week and of the month. After mapping the inbound calls paths, a discrete event simulation model was developed for testing the impact of different nurse schedules on performance measures imposed by Quebec Ministry of Health. Simulations were run using several data sets allowing for different call handling time and users file handling and update distributions. Other parameters such as the number of available nurses and the number and distribution of inbound calls were taken into account.

4 - Patient prioritization in cardiac catheterization labs
Lida Anna Apergi, John Baras, Bruce Golden, Kenneth Wood

This research tackles the problem of prioritizing patients who are waiting to go through procedures performed in a cardiac catheterization lab. Considering the set of cardiac catheterization labs in the cardiology department of a large medical center, where both outpatients and inpatients use the same resources, and different types of procedures take place in the same location, a model is designed and developed towards minimizing the waiting costs of the patients while maximizing the utilization of the resources. Outpatients and inpatients have different priorities resulting from the different objectives of each type of patient. Nevertheless, on the day of the procedure the priorities may change in an effort to create a more efficient schedule. The proposed model takes into account the uncertainty in the duration of the procedures as well as delays resulting from the unpreparedness of the outpatients to go through the procedure on the day of the appointment. An Approximate Dynamic Programming approach is used to prioritize the patients through the different steps they are required to complete.

■ WC-14

Wednesday, 12:30-14:00 - H2.20

Packing and Covering with Integer Programming

Stream: Mixed Integer Programming
Invited session
Chair: *Stefano Coniglio*

1 - Strip Packing with Precedence Constraints
Philipp Fath, David Sayah, Stefan Nickel

It is necessary to stack items in many industrial applications. These stacking tasks are usually embedded in consecutive processes. We examine different scenarios in the steel industry where items, e.g. steel sheets or plates, are transported by conveyors and stacked by gantry cranes. Each scenario determines a distinct partial order on the set of items to be stacked. Under these circumstances, the stacking problem at hand can be defined as a strip-packing problem with precedence constraints (SPP). First, we propose a MIP formulation of SPP that is an extension of a standard MIP formulation of the well-known 2D strip packing problem. Our model takes a graph representation of the given mandatory precedence relationships between items as an input. Any feasible packing produced by the model is consistent with the given precedence graph. Second, we analyse the impact of the structure of the precedence graph on solution runtimes. Moreover, we discuss a simple decomposition technique for the proposed MIP formulation aiming at the acceleration of solution runtimes. Finally, we evaluate the performance of the new formulation of the SPP using a standard MIP solver. To this end, we augment benchmark instances known from the literature by adding generated precedence relationships.

2 - The Complete Vertex p-Center Problem: An Exact Set Covering Method
F. Antonio Medrano

The vertex p-Center problem consists of locating p facilities that cover all n demands in order to minimize the maximum distance between a demand and the facility that covers it. In other words, it is equivalent to finding the minimum coverage radius r and locations of p facilities capable of covering all demands. Originally formulated by Hakimi (1965), this problem is NP-Hard, and the standard formulation has proven to be particularly challenging for IP solvers on large problems. Thus, most solution approaches use heuristics or relaxations (Minieka 1970, Tansel et al. 1983, Mladenović et al. 2003, Elloumi et al. 2004). The complete p-Center problem extends the formulation to solve the for all p-values from 1 to N, where N is the number of nodes to cover. This provides a complete coverage trade-off curve between number of facilities and coverage radius.

This talk proposes an approach for solving the Complete Vertex p-Center Problem using an iterative location set covering approach with selecting only r-values that have the potential to be exact solutions. Experiments on a variety of data sets demonstrate that this new iterative covering method is faster than approaches using traditional p-Center formulations, and in certain instances can be further sped up with brute force combinatorics.

3 - The bin packing problem with item class setups
Stefano Coniglio, Fabio Furini

We introduce and investigate the Bin Packing Problem with Setups (BPPS), a generalization of the Bin Packing Problem (BPP) in which the items are partitioned into classes, each having a setup weight and a setup cost. We first show that the BPPS is in APX, and propose a scheme to combine constant-factor approximation algorithms for the BPP to produce BPPS solutions that are within a constant-factor of the optimum. We then investigate a natural formulation for the BPPS with a variable per item-bin pair, show that its linear programming relaxation can be solved in closed-form in linear time, and establish an asymptotic bound on its optimality gap. We then propose an alternative formulation featuring exponentially-many variables, which we embed into a branch-and-cut-and-price algorithm based on a two-level branching scheme and on the separation of subset row inequalities, which we also enhance via a preprocessing procedure and a bound-tightening one. Extensive computational experiments show the effectiveness of our approach when compared to off-the-shelf methods.

4 - Separating 2-partition inequalities for the clique partitioning polytope
Michael Sørensen

The clique partitioning problem is to partition a complete edge-weighted graph into node-disjoint complete subgraphs (cliques) such that the sum of the weights of all edges within the cliques is maximal (or minimal). We propose a heuristic for separating facet-defining 2-partition inequalities for the associated clique partitioning polytope and evaluate its usefulness in a cutting-plane algorithm.

Our computational experiments fall into two categories: 1) we compare the results of the proposed separator to those obtained by exact polynomial-time separators for other classes of facet-defining inequalities, and 2) we compare them to those obtained by known separators from the literature. In both cases the results are in favour of the proposed separator.

■ WC-16

Wednesday, 12:30-14:00 - Theatre A

Machine Learning and Combinatorial Optimization II

Stream: Combinatorial Optimization II
Invited session
Chair: *Roberto Montemanni*
Chair: *Matteo Salani*

1 - Neural parameters setting
Vittorio Maniezzo, Roberto Montemanni

The no free lunch theorem suggests that we can hardly expect to identify a parameters setting for an optimization algorithm that behaves optimally on all combinatorial optimization problems, or even on all instances of one same problem. There has been continuative research interest in automating the process of parameters setting, with the objective of identifying a setting which is effective on average on all instances of a problem. However, the effectiveness is intuitively dependent on the structure of the instances, therefore instances with widely different structure are best solved with different settings. To account for this, we propose a neural approach, where the neural network suggests the parameter values to use, given the instance to solve. To achieve this, instances of one same problem are preliminarily clustered according to their structure, specifically to statistics computed on the instances, then state-of-the-art parameter optimizers are run on instances of one same cluster, to identify the optimal setting for that cluster. The whole set of pairs instances-settings is then used as a training set for a neural classifier, in the hope that the generalization and abstraction capability of the network will permit to adapt the learnt settings to novel instances, which will be later proposed in input. Preliminary computational results will be presented for a tabu search on quadratic assignment problems and for a Lagrangian heuristic on generalized assignment problems.

2 - Comparing two new combinatorial optimization algorithms to leading machine learning techniques
Philipp Baumann, Dorit Hochbaum, Yan Yang

We compare the performance of recently developed graph-based combinatorial optimization algorithms (SNC and KSNC) to that of leading machine learning techniques. The surprising result of this comparison is that SNC and KSNC show the best or close to best performance in terms of their F1-scores, accuracy, and recall. Furthermore, the performance of SNC and KSNC is more robust than that of the other algorithms; the others may perform well on average but tend to vary greatly across data sets. These results demonstrate that combinatorial optimization techniques can be competitive as compared to state-of-the-art machine learning techniques.

3 - Application of Logistic Regression and Neural Network Models in a Study of Willingness to Pay for Waste Disposal
Iris Yeung, William Chung

This paper studied the factors affecting residents' willingness to pay for waste disposal in Hong Kong by logistic regression and neural network models. The data were collected in a questionnaire survey using simple random sampling method and Computer-assisted Telephone Interview System. 1005 persons were contacted. After eliminating responses which refuse to answer some key questions and more than half of the socio-economic questions, there were 753 valid responses. The target variable was willingness to pay, which was measured by a combination of dichotomous and open-ended questions. The input variables were knowledge of the respondents on waste charge method, landfill fullness and time to build new incinerator, degree of support towards the three government proposed policies (waste charge, landfill extension and new incinerator), daily waste disposal amount, gender, residential, education, age, household size, type of living quarters, and monthly personal income. The models were fitted with or without variable selection and compared using the misclassification rate and average square error as the criteria.

4 - Routing and Spectrum Assignment IntegratingMachine-Learning-Based QoT Estimationin Elastic Optical Networks
Matteo Salani, Cristina Rottondi, Massimo Tornatore

Machine Learning (ML) is under intense investigation in optical networks as it promises to lead to automation of a variety of management tasks, as amplifier gain equalization, fault recognition, Quality of Transmission (QoT) estimation, and many others. Though several studies focus on each of these specific tasks, the integration of ML-based estimations inside Routing and Spectrum Assignment (RSA) is still largely unexplored.

This paper moves towards such integration. We develop a framework that leverages the probabilistic outputs of a ML-based QoT estimator to define the reach constraints in an Integer Linear Programming (ILP) formulation for RSA in an elastic optical network. In this integrated procedure, the RSA problem is solved iteratively by updating the reach constraints based on the outcome of a QoT estimator, to exclude lightpaths with unacceptable QoT. In our numerical evaluation, the proposed integrated method achieves savings in spectrum occupation up to 30% (around 20% on average) compared to traditional ILP-based RSA approaches with reach constraints based on margined analytical models.

■ WC-17
Wednesday, 12:30-14:00 - A005

Planning and Operation of Virtual Power Plants

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: Ana Baringo

1 - Economic Assessment of Flexible Biogas Plants in Virtual Power Plants
Lars-Peter Lauven, Hendrik Butemann, Stephan Fichtner

Flexible power production from biogas can help to balance power grids in periods with low production from intermittent renewables but requires costly refurbishments in terms of generator capacity and gas storages. With a given flexibilization concept, the operation of a flexible biogas plant can be optimized with regard to revenues from power sales. However, the flexibility of power production is constrained by the wear and tear associated with frequent start-ups and shutdowns and by the available storage capacity. As market regulations usually require common marketing of several flexibility options, we analyze the aggregation of flexible biogas plants with other flexibility options in Virtual Power Plants (VPP). In order to quantify the benefit of aggregation for the different participating parties, we apply mixed-integer optimization models for day-ahead bids and subsequent intraday trading for situations with limited market liquidity. To compare the economic benefit of different flexibilization concepts, we present a python algorithm that can iteratively derive optimal unit commitment decisions for flexibility options in a VPP to approximate the economic benefits of aggregation. We apply the algorithm on modifications of publicly available photovoltaic power production data to show the effects of inaccurate forecasts in a case study.

2 - Potential impact and economic potential for integrated wind farm - electrolyser energy system
Vibeke S Noersteboe, Miguel Muñoz Ortiz, Gerardo Perez Valdes

One of the 10 priorities of the European Commission is Energy Union and Climate, whose key policy areas include de-carbonising the economy, increasing efficiency and integrating energy markets. Increased de-carbonisation of the energy system by means of intermittent renewable sources, such as wind and solar, has been causing grid instability and grid capacity limitations. These limitations rapidly reduce the value of wind power beyond a certain market penetration, and hamper de-carbonisation. Generating hydrogen is one way to make use of excess power and to allow a larger penetration of intermittent renewable sources into energy markets.

Haeolus is a EU project that proposes a new-generation electrolyser integrated within a state-of-the-art wind farm in a remote area with access to a weak power grid.

The potential impact of the Haeolus concept on the European and international energy systems, especially in regard to the penetration of wind power into the energy mix will be analysed by means of an investment optimization model for the European electricity sector. Furthermore, Haeolus will analyse and optimize operation concerning varying weather and power-price forecasts, and quantify the economic opportunities and potential for wind farm operators, with particular focus on grid balancing services and on hydrogen market. The analyses are performed using the optimisation tool HyOpt, optimizing design and operation of the concept.

3 - Biogas plant optimization by increasing its flexibility - a strategic planning problem in biomass-to-energy Supply Chains
Stephan Fichtner, Herbert Meyr

Increasing shares of volatile energy resources like wind and solar energy will require flexibly schedulable energy resources to compensate for their volatility. Biogas plants can produce their energy flexibly and on demand, if their design is adjusted adequately. By doing so, the biogas plant operator has the opportunity to generate more earnings by producing and selling electricity in higher price periods. In order to achieve a flexibly schedulable biogas plant, the design of this plant has to be adjusted to decouple the biogas and electricity production. Therefore, biogas storage possibilities and additional electrical capacity are necessary. This research addresses the investment decisions to increase the flexibility of a biogas plant by installing biogas storages and additional electrical capacities under consideration of revenues out of direct marketing at the energy spot market. In order to support the strategic, long-term investment decisions, an operative plant schedule for the future, considering (non-) linear technical characteristics and the legal framework is optimized in an uncertain environment.

4 - Expansion Planning of a Virtual Power Plant: A Stochastic Risk-Constrained Approach
Ana Baringo, Luis Baringo, José Manuel Arroyo

A novel approach for the expansion planning of a virtual power plant that participates in the energy electricity market is proposed. The virtual power plant comprises a conventional power plant, a renewable generating unit, a storage unit, and flexible demands, and analyzes the possibility of building new conventional, storage, and renewable units with the aim of maximizing its expected profit while minimizing the risk associated with its expansion decisions. Uncertainty related to future variable costs of the conventional power plants, future peak demand of the flexible demands, and future energy market prices is modeled using a set of scenarios. The resulting model is formulated as a two-stage stochastic problem in which the conditional-value-at-risk metric is used to model the profit risk associated with the expansion decisions. Results from a case study are provided to show the effectiveness of the proposed approach.

■ WC-18

Wednesday, 12:30-14:00 - C112

Statistical Disclosure Control I

Stream: Data Mining and Statistics
Invited session
Chair: *Anna Oganian*
Chair: *Goran Lesaja*

1 - Randomized Response for Big Data: Dimensionality Mitigation with Minimum Accuracy Loss
Josep Domingo-Ferrer, Jordi Soria-Comas

Randomized response (RR) is a local anonymization mechanism that respondents to a survey can use to protect their privacy when asked about sensitive attributes. Basically, they randomize their answer according to a prescribed probability matrix and they report the randomized answer. A strong point of RR is that the data collector can still obtain an unbiased estimation of the distribution of true responses based on the randomized responses. If the estimated distribution is accurate, statistical computations on it will yield results close to those that would have been obtained on the true data (without requiring respondents to disclose their true data). However, large dimensionality (that is, a large number of attributes) decreases the accuracy of the estimated distribution. We adopt an approach consisting of identifying clusters of attributes so that attributes in different clusters can be regarded as independent, which brings dimensionality reduction by performing RR separately within each cluster of attributes. A shortcoming is that, the less independent the attributes in different clusters, the less accurate will be the estimated distribution of the true data. We explore algorithms to minimize the estimation accuracy loss in the common situation of assuming independence between attributes that are not exactly independent.

2 - Graph Perturbation for Social Networks: Noise Addition
Vicenç Torra, Julián Salas

All kinds of information can be represented by means of graphs. The most typical case is social networks, where individuals are represented by nodes and connections are represented by edges. Nevertheless, other types of data can also be represented in terms of graphs. For example, location data (i.e., trajectories).

To release graphs in a way that disclosure does not take place, we need to apply data protection mechanisms. Masking methods is the term used in statistical disclosure control for methods that modify the original data in a way that disclosure risk is reduced while data utility is kept as much as possible. The literature offers several masking methods, one of them for numerical databases is noise addition.

In the case of graphs, the literature offers a large variety of data protection techniques. They are based on modifications of the graph structure by adding/removing edges/nodes. When protection methods are restricted to adding edges, the protected graph is a supergraph of the original; when restricted to deleting edges, the protected graph is a subgraph of the original and all the published relations will be truthful.

In this work we will discuss the formalization of masking methods for graphs in terms of noise addition with different constraints. This formalization provides us with a tool to study graph perturbation from a different perspective. It permits to model masking and to study information loss from the point of view of the noise added.

3 - Solving the Cell Suppression Problem by a stabilized Benders method
Daniel Baena Mirabete, Jordi Castro, Antonio Frangioni

Motivated by the well-known issues of Benders' decomposition, which suffers from the same drawbacks of the cutting-plane method, i.e., oscillation and slow convergence, we present a stabilized Benders decomposition whose master is restricted to a neighborhood of hopefully good solutions by local branching constraints. During the iterations, these local branching constraints are updated and even dropped in order to speed-up the convergence to the optimal solution. Stabilized Bender's method was successfully applied to the Cell Suppression Problem (CSP), a challenging MILP method in statistical tabular data protection. Benders' decomposition is the only method able to solve efficiently non-toy CSP instances. Our experiments with randomly generated and real-world CSP instances with up to 24000 binary variables, 181M continuous variables and 367M inequality constraints show that our approach is competitive with both the current state-of-the-art (cutting-plane-based) code for cell suppression, and the Benders implementation in CPLEX 12.7. In some instances, stabilized Benders is able to quickly provide a very good solution in less than one minute, while the other approaches were not able to find any feasible solution in one hour.

4 - Computational comparisons of different models for solving continuous CTA problem
Ionut Iacob, Goran Lesaja, Anna Oganian

In this talk we consider a Controlled Tabular Adjustment (CTA) model for statistical disclosure limitation (control) of tabular data. The goal of the CTA model is to find the closest safe table to some original tabular data set that contains sensitive information. The closeness of original and masked table is usually measured using L_1 or L_2 norm; with each measure having its advantages and disadvantages. We present Second Order Cone reformulation of L_1 CTA and compare it with traditional Linear Programming formulation of L_1 CTA. Computational experiments using interior-point methods show competitiveness of the second order cone model for L_1 CTA when compared to existing models. Furthermore, we explore other measures of closeness between the original and masked tables which are based on table statistics such as chi-square.

■ WC-19

Wednesday, 12:30-14:00 - C115

Emerging Applications in Management Science: Logistics

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: Sakine Batun

1 - **Stochastic Disassembly Line Balancing Problem with Hazardous Tasks**
Eda Göksoy Kalaycılar, Sakine Batun, Meral Azizoglu

We consider stochastic disassembly line balancing problem with fixed number of workstations and hazardous tasks whose successful completions are subject to uncertainty. We assume that each task brings a revenue if it releases a demanded part and incurs a disassembly cost. If all hazardous tasks are successfully completed, the unit is disassembled as planned. However, if any hazardous task fails, the unit disappears from the line since it is damaged and no more tasks can be performed on it. We formulate this problem as a two-stage stochastic integer program where the successful completion of each hazardous task follows a Bernoulli distribution and the objective is to maximize the expected profit. We conduct numerical experiments to estimate the value of the stochastic solution and to investigate the impact of hazardous tasks on the design of the disassembly line.

2 - **Optimal inspection trajectories for three-dimensional complex objects in additive manufacture**
Bruna Ramos, A. Ismael F. Vaz

The 3D printing technology is innovative and allows the creation of customized (complex) objects. Manufacturing costs reduction and high levels of customization on a wide variety of materials makes this process attractive to market in several areas. Despite of the high reliability and performance levels of this technology it is necessary to ensure that printed objects meet some quality industrial requirements. Non-destructive tests may be performed to determine whether the printed object conforms to requirements. Inspection (e.g. using a thermographic camera) of 3D printed objects is a relatively common task, but computing equipment movement inspection trajectories is not trivial.

The main objective of this work is to propose a technique to compute optimal inspection trajectories for complex three-dimensional objects through non-destructive techniques. An inspection machine with the three standard axes and two additional axes is considered, allowing a better positioning of the inspection equipment. Minimal inspection time is considered subject to collision free inspection trajectories. We consider heuristics and exact methods (integer programming model) to determine the optimal inspection trajectory. We provide a discussion about the proposed strategies through three relevant case studies.

3 - **State-of-the-art and definition of key design parameters for the development and testing of vision picking technology in warehouse operations**
Anastasios Gialos, Vasileios Zeimpekis

Over the last years the complexity of warehouse operations have increased significantly due to the increase of e-commerce, customer requests for frequent and low volume order fulfillment as well as the need for faster response times. Although all warehouse processes are critical and affect the total logistics cost, order picking process contributes highly in both logistics costs (55% to 65% of the total operational warehouse costs) and customer service. The development of IT during the last decades brought a remarkable number of applications in product picking process such as voice and light picking. Yet, there is still a need for better productivity and less operational cost and vision picking through smart glasses and augmented reality seems to be a promising technology. The latter uses wearable technology and combines the very best of vision-guided picking to produce a faster, hands-free and accurate solution for industrial operations. To this end, the aim of this paper is to present a Systematic Literature Review of parameters that can be taken into consideration for vision picking system design, development and testing. Furthermore, the paper classifies the most important key parameters on three categories: a) system parameterization, b) operational scenarios and, c) comparative assessment with other picking systems. Last but not least, the paper provides a detailed framework for testing vision picking technology both in lab as well as in field environment.

■ WC-20

Wednesday, 12:30-14:00 - C006

Warehouse optimization

Stream: Automated Warehouse System
Invited session
Chair: Ruslan Krenzler

1 - **Efficient order picking methods in robotic mobile fulfillment systems**
Lin Xie, Nils Thieme, Ruslan Krenzler, Hanyi Li

Robotic Mobile Fulfillment Systems (RMFS) are a new type of warehousing systems, which has received more attention recently, due to increasing growth in the e-commerce sector. Instead of sending pickers to the inventory area to search and pick the ordered items, robots carry shelves (called "pods") including ordered items from the inventory area to pick stations. Human pickers work only in the pick stations. This type of warehousing systems relieves the human pickers and improves the picking process. There are four decision problems for each new incoming order. We have to decide which robot carries which pod along which path to which station to finish picking. We concentrate in this paper on decisions about pods (pick pod selection) and stations (pick order assignment). In previous research for an RMFS with multiple picking stations, these decisions are made consecutively. Instead, we present a new integrated model to minimize the number of necessary pod-station-visits while trying to utilize the maximal capacity of the pick stations. Moreover, we extend our model to allow splitting orders. That means parts of an order are allowed to be picked at different stations and then merged in a different place. We test our models with different instances in our open-source simulation framework RAWSim-O.

2 - **Stochastic Optimization for Pod Repositioning in Robotic Mobile Fulfillment Systems**
Ruslan Krenzler, Lin Xie, Hanyi Li

We analyze robotized warehouses, where robots move shelves between a storage area and output stations. At every output station there is a person - the picker - who takes items from the shelves and packs them into boxes according to customers' orders. The content of each shelf is different. The customer's orders are random. As a result, some shelves are used more frequently than the others are. When the picker does not need a shelf any more, a robot carries this shelf back to the storage area. In the storage area, there are several free places and we need to decide where to put this shelf. Every decision influences the next one. The sequence of these decisions influences the overall efficiency of the warehouse. We look for an optimal sequence.

The customers and pickers add randomness into the system and a deterministic model of the whole process appears to be not sufficient. We develop a stochastic model to better understand the complex real-world warehouse and develop realistic optimization algorithms. We test our results with a simulation framework.

3 - Warehouse optimization through anticipatory order picking
Christof Defryn, Son Tran, Rui Jorge Almeida

The growing importance of e-commerce puts warehouses under high pressure. First, small order sizes typically result in efficiency loss of the process of retrieving the requested products from storage. Second, the extreme short lead times require warehouses to respond to incoming customer orders within hours or even minutes, while keeping operational costs at their minimum. This high degree of dynamism, however, leads easily to ad hoc decisions and missed opportunities for optimization.

In this research, we focus on the development of decision-support systems for anticipatory order picking, i.e., the retrieval of products from storage before the customer actually placed the order. Next to already confirmed customer orders, a dynamic list of expected (uncertain) orders is generated based on developed forecasting techniques that use historical and real-time data. Next, each time a picker becomes idle, a new pick tour is constructed based on known and expected orders.

The advantage is twofold. First, increased opportunities for warehouse optimization appear through better batching procedures as the pool of potential orders that can be picked together is larger. Second, once a customer eventually orders such an anticipated product, the required time to prepare the order and ship the products to the customer will be lower as the product has already been retrieved from storage.

■ WC-21

Wednesday, 12:30-14:00 - F101

Algorithms for Single- and Multiobjective Shortest Path Problems

Stream: Algorithms on Graphs
Invited session
Chair: *Andrea Raith*
Chair: *Krunoslav Puljic*

1 - Modelling path-dependent cold start emissions in traffic assignment
James Tidswell, Andrea Raith, Anthony Downward

There has been increased awareness of greenhouse gases and associated climate change, with the transport sector making a significant contribution to greenhouse gases via vehicle emissions. This has provoked interest in estimating vehicle emissions through the use of traffic models such as the traffic assignment model. Emission models in this context generally consider the 'hot' emissions, which are the emissions produced while the vehicle engine is at operating temperature, and are a function of average speed. In this research we consider accounting for the initial portion of a vehicle user's trip where the engine starts below operating temperature, producing excess 'cold' emissions, which are generally a function of trip length. We examine one method of modelling cold emissions, which requires addressing the path-dependent shortest path problem that arises with path-length-dependent emission costs on arcs. We propose an algorithm to identify the shortest path in a network with path-dependent emission arc costs. This algorithm builds on the A-star algorithm for shortest paths. As minimal-hot-emissions paths are easy to calculate, they can be evaluated with a cold emissions cost to give an upper bound, with minimal-hot-emissions path costs used as a lower bound. Incorporating this algorithm into the traffic assignment model allows the calculation of solutions to the traffic assignment problem with path-dependent emission objectives.

2 - The Universal Near-Shortest Path Problem
Luca Schäfer, Stefan Ruzika

In this presentation, we investigate the universal near-shortest path problem, which generalizes the classic near-shortest path problem by introducing a universal weight vector. The proposed generalization covers a variety of well-known shortest path problems such as bottleneck, k-max, k-sum and sum objectives. We propose a recursive algorithm to compute the set of all universal near-shortest simple paths from source to sink and prove the correctness of the algorithm. We show that the running time complexity per path enumerated is polynomially bounded as long as the underlying shortest path problem can be solved in polynomial time. Further, we study the size of a minimal complete set with respect to different configurations of the universal weight vector. Moreover, a variant of the universal near-shortest path problem, the so-called "universal next-shortest path" problem, is displayed. Again, we analyze the complexity of this problem with respect to different values of the universal weight vector. This research was partially supported by the Bundesministerium für Bildung und Forschung (BMBF) under Grant No. 13N14561.

3 - Software implementation of an algebraic approach to path problems
Krunoslav Puljic, Robert Manger

Path problems are a family of optimization or enumeration problems, which reduce to generation and evaluation of paths in graphs. Some examples are: checking path existence, finding shortest or longest or most-reliable paths, finding paths of maximum capacity, listing all paths, etc. It is well known that various types of such problems can be treated together within a common algebraic framework. Then, each particular type is characterized by a different "path algebra", i.e. a different instance of the same abstract algebraic structure. A consequence is that all types of problems can be solved by the same general algorithms working over an arbitrary (abstract) path algebra.

In this work we present an efficient software realization of the above described algebraic approach to path problems. Our software package implements a large collection of path algebras: first simple ones (i.e. scalar algebras), then those more complex that are built upon simpler ones (e.g. vector or set or vector-set algebras). The package also implements a suite of general path-finding algorithms - most of them are analogues of matrix inversion algorithms from conventional linear algebra. All software components are designed in a flexible manner, so that they can be combined in different ways. With such combinations it is possible to construct ad-hoc solutions to various types of path problems, including also their multi-objective or robust variants.

■ WC-22

Wednesday, 12:30-14:00 - F102

Remanufacturing and Recycling

Stream: Sustainable Supply Chains
Invited session
Chair: *Mafalda Carvalho*

1 - Improving Remanufacturing Core Recovery and Profitability Through Seeding
Neil Geismar, James Abbey, Gilvan C. Souza

Durable goods firms sell new products as remanufactured at the start of a new product's lifecycle (seed) to start efficient remanufacturing earlier and to fulfill demand for remanufactured products earlier in the product's lifecycle. The cost of producing a new unit and the product lifecycle curve determine profitability of seeding.

2 - Entering the High-end Market by Collecting and Remanufacturing a Competitor's High-end Cores
Xiang Zhu, Weihua Zhou

Motivated by the smartphone industry, this paper studies a duopoly channel consisting of a high-end firm and a low-end firm. The high-end firm sells its own brand at a high profit margin. The low-end firm sells its own brand at a low profit margin, but can choose to differentiate by collecting and remanufacturing high-end cores, thereby entering the more lucrative high-end market. We investigate how the equilibrium strategies of both firms are influenced by the cost structure and customers' valuation. We derive condition for the low-end firm to engage in remanufacturing high-end cores, and show how the high-end firm reacts to limit the loss of market share.

3 - Two-stage multi-attribute decision making: An application to select appropriate locations for municipal solid waste management facilities

Vinay Yadav, Subhankar Karmakar

Selecting appropriate locations for municipal solid waste (MSW) management facilities, such as transfer stations, from a set of available potential locations is a difficult task. The conventional approaches for locations evaluation focus primarily on the economical attributes and hence fail to account for other realistic factors. Also, individual scoring of locations is prevalent in literature without considering the impacts of different possible combinations of locations on overall ranking. To address these issues, this study proposes a two-stage multi-attribute decision making (MADM) model which extensively evaluates environmental, social, and technical attributes along with conventional economical attributes. The MADM model ranks all the alternatives derived from all possible combinations of these locations. The proposed MADM model is illustrated on a real case study of Nashik city, India. Results provide the ranks of all feasible combinations along with their probabilities of rank reversibility. The mean and standard deviation of relative closeness are further evaluated for top ranks. The present study bestows all level of stockholders with a holistic approach to find suitable locations of MSW management facilities while considering economical, environmental, social and technical attributes.

4 - Waste and By-products Mapping towards sustainable Supply Chain Management

Mafalda Carvalho, Ana Barbosa-Póvoa, Susana Relvas, Sara Martins

The agro-food sector is highly competitive and globalized, with a very complex supply chain (SC). Although it is extremely fragmented, with a high number of entities and stakeholders along the SC, it is at the same time concentrated, with most of the agro-explorations in a region belonging to a restrict number of stakeholders, with a very low level of collaboration. The increasing consumers' concern with sustainability has been pressing the sector to innovate and create new SC solutions in this field. SC waste and by-products mapping emerges as a possible solution to promote more Sustainable Supply Chain Management, concerning the three sustainability' pillars: economic, environmental and social. Through the development of a generic and operational mapping tool able to systematically identify where, why and in which amount the waste and by-products are generated, a Decision Support System (DSI) is designed with the aim of assisting companies in optimizing their waste strategies. In other words, the main goal of this work is to develop a DSI capable of defining the best valorization treatment available that maximizes the sustainable value retrieved from the multiple opportunities evaluated, promoting at the end more sustainable and collaborative holistic SCs.

■ WC-23

Wednesday, 12:30-14:00 - F103

Frontiers of Risk Management

Stream: New Challenges in Investment Strategies, Risk and Financial Modelling

Invited session

Chair: Francesco Cesarone

1 - A copula approach to integration and diversification in financial markets

Giulia Rotundo, Roy Cerqueti

The financial interdependencies in the Stock market given by the cross-ownership and cross-shareholding have different and non monotonic effect on the propagation of cascades. In fact, the diversification of companies' portfolios causes a reduction of the sensitivity to its own investments, and an exposure to the fluctuations of the others; however, large diversification makes the company reduce the overall correlation, and the contagion becomes less likely. In a specular way, the integration of companies in the market (though the sale of their shares) increases the dependence on the other organizations. The trade-off among diversification and integration tunes the different patterns propagation of contagions and cascades. Since many configurations may give rise to similar levels of risk, a probabilistic approach is most needed. This work bases on a copula approach for exploring the risk due to such financial interdependencies and the raise of concentration. The matter is of interest to regulatory bodies, in view of the guidelines on bergers and acquisitions. The calibration of the models on a dataset serves to outline the application of the theoretical approach.

2 - Measuring Risk with COGARCH models

Lorenzo Mercuri, Francesco Bianchi, Edit Rroji

We introduce a multivariate Independent Component COGARCH(p, q) model for financial time series. The ICA-COGARCH model is able to capture heteroskedasticity and dependence in high-frequency unequally spaced financial time series. We apply the model in the scenario generation at any time-horizon and construct a decision-tree in order to determine optimal portfolio weights obtained as a solution of a static maximization problem. The objective function is a linear combination of expected terminal wealth and a specific risk measure.

3 - Risk Parity with Expectiles

Francesco Cesarone, Fabio Bellini, Fabio Tardella, Christian Colombo

A recent popular approach to portfolio selection aims at diversifying risk by looking for the so called Risk Parity portfolios. These are defined by the condition that the risk contributions of all assets to the global risk of the portfolio are equal.

The Risk Parity approach has been originally introduced for the volatility risk measure. Here we show how to define Risk Parity portfolios when the expectiles are used as (coherent) risk measures, and we investigate some of their properties.

Furthermore, we propose several methods for practically finding Risk Parity portfolios with respect to expectiles and we compare their accuracy and efficiency on real-world data.

4 - Efficient portfolios and leverage analysis

Mario Maggi, Pierpaolo Uberti

The classical mean variance portfolio theory does not take explicitly into account the leverage of a portfolio. As a result, the efficient frontier is composed by portfolios that are not comparable in terms of leverage. In general, standard asset allocation models neglect to consider and control the leverage of the proposed portfolios. The comparison of portfolios with different leverage causes a bias in the mean variance dominance scheme. In this paper we formally propose a definition of the leverage of a portfolio and we use it in two ways. First we develop a technique in order to compare portfolios with different leverage, separating the contributions of diversification and leverage. Secondly, we tackle the problem of building a portfolio efficient frontier, under leverage constraints; this problem appears hard to solve both analytically and numerically.

■ WC-24

Wednesday, 12:30-14:00 - F103A

Supply Chain Risk and Performance Management

Stream: Supply Chain Management
Invited session
Chair: Harshal Lowalekar

1 - Influences of Supply Chain Finance on the Mass Customization Program: Risk Attitudes and Cash Flow Shortage
Shu Guo, Na Liu

Nowadays, with the addresses on satisfying diversified customer needs, an increasing number of brands has launched the mass customization (MC) programs. In the meantime, however, considering the high market uncertainty in consumer preferences and the production challenges, there are plenty of risks in MC operations. In this paper, we develop a game theoretic model consisting of a MC brand and an upstream manufacturer, and aim to identify the influences of supply chain finance on the MC programs. The influences brought by the risk attitudes of both the MC brand and the manufacturer are analyzed. Besides, an extra interest rate for raising the working capital for production at the manufacturing level is also considered in this paper. We find that when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high, the optimal product modularity level of the MC product is increasing with the MC brand's degree of risk averse. In addition, the higher the interest that the manufacturer needs to pay for raising the working capital for the MC production process, the lower the optimal wholesale price of each finished MC product will be so as to help the manufacturer raise more money through the advance order from the MC brand. These findings complete the findings in extant literature and provide important managerial insights in managing MC operations.

2 - Mapping supply chain risk mitigation strategies with the enablers by considering the mutual interrelationship between them
Pradeep Kumar Tarei, Jitesh J. Thakkar, Barnali Nag

Risk mitigation (RM) is a vital step in Supply Chain Risk Management (SCRM) process, which comprises the selection of a suitable RM strategy to nullify the impending and adverse impact of risk. The existing literature has experienced an exchangeable usage of RM strategies with RM enablers (practices). In this regard, the current research distinguishes the difference between the aforementioned terms without compromising with their conventional definition and additionally reveals the underlying relationship between them. Both proactive and reactive risk attitudes are considered simultaneously. A systematic literature review approach is adapted to explore various RM enablers, and they are further mapped to their respective RM strategies by using correspondence analysis technique. Additionally, the proposed research model is validated against a real-life case in the Indian scenario. The results obtained from the study reveals three underlying factors between the RM strategies viz. adaptive capability to deal with risk, short/long term treatment of risk and the sophistication of the implementation of the RM enablers. RM enablers such as supplier evaluation, technology adaption, flexible process, and information security, etc. correspond to Risk Avoidance strategy; Whereas Risk sharing includes revenue sharing, insurance, collaboration, public-private-partnership, etc.. The unique contributions of this study are presented as theoretical implications and managerial propositions.

3 - Buyer-backed Purchase-order Financing For Supplier Facing Yield Uncertainty
Richa Jain, Matthew Reindorp, Arun Chockalingam

Adequate access to working capital is often a challenge for Small and Medium sized Enterprises (SMEs). Schemes such as factoring and reverse-factoring offer a solution on the post-shipment side of the financing cycle. We consider the pre-shipment side of the cycle: provision of capital through purchase order financing. In our model, the explicit obstacle to financing is the risk that the SME supplier will experience a yield shortfall. We investigate the possibility the customer of an SME may offer 'buyer-backing' for purchase order financing, i.e., a sharing of the risk faced by an external provider of capital. The customer's operational and financial decisions must ensure economical feasibility for the supplier as well as for the provider of capital. We establish that provision of buyer-backing creates value for customer and supplier in terms of financial gains and ability to continue business. Through numerical analysis, we quantify the risk created by buyer-backing and identify a mitigation strategy.

4 - Performance Measurement in Supply Chains
Harshal Lowalekar

In this research we show how majority of problems in the supply chains arise out of individual targets based on functional measurements. It is shown how the problems of shortage and excess of stock, long lead times, poor responsiveness, huge inventories, poor cash position, internal conflicts, month-end syndrome and bullwhip effect arise due to targets based on traditional measurements that can be found in production, purchasing, distribution, sales and marketing functions. Using the Theory of Constraints (TOC) cause and effect method we identify those measurements which seem to result in a vast majority of problems found in such supply chains. It is then shown using a real life implementation how the new TOC based measurements can lead to significant improvement in supply chains and eliminate most of these problems. It is also shown that the supply chains can do away with the usual local measurements and instead use a set of global and local measurements which can help in aligning the various functions of the supply chains in the direction of the common goal. Caution must be taken, however, to not convert the measurements into targets.

■ WC-25

Wednesday, 12:30-14:00 - F104

Logistics

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: Stefan Bugow

1 - Simulation-based decision support tool for in-house logistics 4.0 in a manufacturing context
Fábio Coelho, Susana Relvas, Ana Barbosa-Póvoa

Product based manufacturing industries rely on strong internal logistics operations that allow efficient production strategies, as assembly line feeding policies and inventory control. Prompt decision-making in flexible manufacturing raises the need for integrated planning and scheduling for overall shop-floor operations. This work explores this need and focuses on a mixed-model assembly line feed by an internal logistics supermarket. A realistic problem formulation is proposed, which is solved by using simulation-based model. This simulation model represents a real size logistic supermarket in the automotive industry, with fleets of robots and allows to test the scalability of the developed algorithms in full production systems. This is done using Simio - simulation modelling framework based on intelligent objects. The information obtained from this model is fundamental to facilitate the decision-making process regarding the usage of robots, the mix of robots and humans and the collaborative settings in the working area.

2 - Trucking optimization based on logistics costs — An empirical investigation
Carlos A. Gonzalez-Calderon, Ricardo Quintero-Giraldo, John Jairo Posada-Henao

Cities are considered as big freight generators and attractors. According to the United Nations, 66% of the word population are expected to life in urban areas in 2050. As a result, every year inter-city goods movements increase their importance to maintain the economic chain. This paper analyses the trucking fleet costs in Colombia. In doing so, the authors analyzed optimal costs and number of vehicles (per truck type) needed to transport different amounts of cargo by commodity group between cities based on the capacities and transportation costs of the trucks. The Ministry of Transportation of Colombia developed an information system to estimate efficient costs for trucks. The system provides trucking costs between 31 main cities for 6 truck types, cargo type and bodywork. The authors used a national freight survey to find the number of commodities and trips/tons transported between the cities. These commodities were classified in different groups. With this information and the system, the authors estimated the average costs of transporting the commodities between Colombian cities. Comparing the transportation cost and the selling cost of each commodity, the authors found the impact of the trucking cost, i.e., the percentage of intercity transportation cost in the supply chain cost for different goods. Moreover, the authors found the optimal number of vehicles (per truck type) needed to transport different amounts of cargo for each commodity group between the cities.

3 - Research in Logistics 4.0: A systematic literature review and a framework for corporate digital transformation
Dimitris Karampourniotis, Vasileios Zeimpekis

Globalization, the rise of e-commerce, cyber threats, and constantly higher customer demands push companies into adopting emerging technologies and automation into their supply chain and logistics operations, which enable them to increase their productivity and minimize their operational cost. Logistics 4.0, a term derived from the combination of Industry 4.0 technologies and innovations and their application on inbound and outbound logistics is a narrower concept than Industry 4.0, as it focuses on typical features, such as automation and digitalization in logistics operations. The technologies most commonly utilized are the Internet of Things (IoT), Big Data analytics, Augmented Reality (AR), Unmanned Aerial Vehicles (UAVs) and Advanced Robotics. The purpose of this paper is to provide an overview of the field by describing dominant Logistics 4.0 technologies and their application in logistics operations, identify gaps in order to propose a future research agenda, and provide insights into the needs of practitioners. A systematic literature review (SLR) targeting articles and reports based on Logistics 4.0 has been constructed, and a content analysis was performed to categorise technologies and applications in the research on Logistics 4.0. Furthermore, a framework that presents the steps that companies should follow for their digital transformation in logistics operations is also presented. The paper concludes with a future research agenda.

4 - Truck scheduling in cross-docking terminals considering flexible unloading speeds
Stefan Bugow, Carolin Kellenbrink

In the parcel service industry, cross-docking terminals are widely used to consolidate parcel flows from different locations. After being unloaded from the inbound trucks, the parcels are transported to the outbound trucks according to their destinations, predominantly using conveyors. In this regard, our research focuses on the scheduling of incoming trucks at the inbound doors. Possible objectives are the minimization of the overall completion time or of the delay of the outbound trucks. In the context of scheduling the inbound trucks, several characteristics of the terminal have to be considered. Important restrictions are conveyor capacities as well as fixed departures of the outbound trucks. First numerical studies show that flexible unloading speeds are a promising option to efficiently use the conveyor capacities. In this talk, a mathematical model for the problem setting with a special consideration of flexible unloading speeds is proposed. Further, the formulation is evaluated by comparing it to a model which does not consider flexible unloading speeds. Finally, the formulation is validated using a simulation model.

■ WC-26
Wednesday, 12:30-14:00 - F106

Moments in History of OR: Europe

Stream: Moments in History of OR
Contributed session
Chair: *Roberto Rossi*
Chair: *Gerhard-Wilhelm Weber*

1 - In Dublin's Fair City: Dublin 1972 to Dublin 2019
Graham Rand

The sixth conference of IFORS (the International Federation of Operational Research Societies), held in Dublin in 1972, was significant, not only for the development of OR in Ireland, but also for IFORS, as EURO was a direct result. Following comments about the 1972 conference, some reflections will be given on the creation and development of EURO.

2 - Can We Find The Unknown (Great)n Grandfather of OR?**
David Lane

The roots of OR lie in the Second World War and the work of Patrick Blackett, widely viewed as the 'Father of OR.' Operational Research as then conceived was about the use of analysis to organise effectively machines, information and decision making. Whilst it could involve technological innovation it was perhaps more interested in getting more out of what already existed. All of these features can be seen in one of Blackett's key contributions: the organisation of the air defence system of the UK, work which played a key role in the Battle of Britain in the summer of 1941. However, very similar work can be found centuries, in fact millennia, before this. The same features of effective organisation of existing devices to improve results, combined with the use of some new innovations, can be observed. These have the guiding hand of one brilliant figure. Archaeology, dusty tomes and a willingness to wander around sun-drenched ruins are necessary to put the story together. The figure that emerges studied war-related operations and carried out analysis which greatly improved the defensive system of his home. He is, perhaps, the (Great)**n Grandfather of OR and drawing him into the history of our field makes for an extraordinary story, links us into mathematics in the Ancient World and is immensely compelling stuff. Who is this unknown figure? Come along to find out the secret.

3 - Computational Science in the 18th Century Test Cases for the methods of Newton, Raphson and Halley: 1685 to 1745
Trond Steihaug

This is an overview of examples and problems posed late 1600 up to mid 1700 for the purpose of testing or explaining the two different implementations of the Newton-Raphson method, Newton's method as described by Wallis in 1685, Raphson's method from 1690 and Halley's method from 1694 for solving nonlinear equations. It is demonstrated that already in 1745 it was shown that the methods of Newton and Raphson were the same but implemented in different ways.

■ WC-27
Wednesday, 12:30-14:00 - F107

Commodities, Financial Modelling and Portfolio Choice

Stream: Commodities and Financial Modelling
Invited session
Chair: *Gonzalo Cortazar*

1 - Life-cycle Consumption and Asset Allocation Problem: Habit Formation and Term Life Insurance
Nalan Gulpinar, Zhezhi Hu, Arie Gozluklu

This paper studies a life-cycle consumption and asset allocation problem introducing habit formation preferences, bequest motive and demand for term life insurance. We model the investor not only as risk-averse, but also averse to ambiguity about stock returns. We introduce a multistage stochastic programming model for the life-cycle consumption and asset allocation problem. Our empirical study show that the demand for term life insurance increases with ambiguity aversion while it decreases substantially with higher degrees of habit formation. We also show that subjective survival belief and borrowing option also affect investor's decisions.

2 - Time-Varying Term Structure of Oil Risk Premiums
Gonzalo Cortazar, Hector Ortega, Eduardo Schwartz

This paper proposes to extract time-varying commodity risk premiums from multi-factor models using futures prices and analyst's forecasts of future prices. The model is calibrated for oil using a 3-factor stochastic commodity-pricing model with an affine risk-premium specification. WTI futures price data is from NYMEX and analyst's forecasts from Bloomberg and the U.S Energy Information Administration. Weekly estimations for short, medium and long-term risk premiums between 2010 and 2017 are obtained. Results from the model calibration show that risk premiums are clearly stochastic, that short-term risk premiums tend to be higher than long-term ones and that risk premium volatility is much higher for short maturities. An empirical analysis is performed to explore the macroeconomic and oil market variables that may explain the stochastic behavior oil risk-premiums.

3 - Can alternative energies play a key role in equity-based portfolios? A dynamic Modified Sharpe Ratio optimization approach
Carlos Esparcia Sanchís, Antonio Díaz

During financial crisis timeframes, markets experience periods of huge instability, so the inherent market risk increase day by day. An alternative that allows mitigating risks is based on the composition of investment portfolios including safe haven securities or hedging instruments. One of the main reasons to add energy assets to an equity-based portfolio is the diversification, as they are usually uncorrelated among themselves. This paper empirically investigates the asset allocation problem in a multi-ETF portfolio strategy under higher order distribution moments. In particular, the aim of this paper is to analyse the effects derived from the inclusion of alternative energies in equity-based portfolios through a time-varying maximization of the modified Sharpe ratio (MMSR) and strongly related to the modelling of higher order distribution moments. This optimization is considered from the implementation of multivariate statistical models such as the GO-GARCH. Further, the results are compared with those obtained in several traditional anlyses, such as the minimum-variance (MV), minimum value at risk (MVaR) and maximum Sharpe ratio (MSR). Lastly, this research is focused on presenting the co-asymmetry and co-curtosis matrix tensors, M3 and M4, estimating the elements of these matrices through three alternative methods: sample estimators, single factor estimators (Martellini and Ziemman, 2010), and a multivariate Gamma Variance distribution (Mercuri, 2011).

4 - Analysis of the Expected Dividends in a Continuous-Time Insurance Model
Boris Shigida, Ekaterina Bulinskaya

To model the surplus of an insurance company, we use the Cramér-Lundberg model with exponential claims. Additionally, when the surplus reaches a fixed barrier and stays above it long enough, the overshoot above that barrier is paid as dividends. When the surplus of the company has been below zero long enough, we say that Parisian ruin has occured. The main theoretical result is an explicit formula for the expectation of total dividend payment before Parisian ruin, as a function of the parameters of this model. We analyze this function numerically and investigate another important characteristic: the optimal barrier (which maximizes the expectation). Also, we use simple statistical estimates to tackle the case of incomplete information, when some parameters of the model are unknown.

The research was partially supported by the Russian Foundation for Basic Research under grant 17-01-00468.

■ WC-28

Wednesday, 12:30-14:00 - G102

Corporate Distress

Stream: Operational Research in Financial and Management Accounting
Invited session
Chair: Markku Kallio

1 - The prediction of corporate distress: reviewing the methodological issues in a multi-period assessment framework
Mohammad Mahdi Mousavi

The design of reliable models to predict corporate distress is crucial as the likelihood of filing for bankruptcy increases with the level and persistence of distress. Recent studies have investigated the impact of several methodological issues such as sampling, feature selection, modelling framework, and performance evaluation criteria on the performance of prediction models; however, the employed assessment frameworks are static, which, by product, do not take time into account. In this paper, we employ a Malmquist DEA as a multi-period assessment framework to investigate the effect of some regarded methodological issues on the performance of distress prediction models.

2 - Support Vector Machines as the decision tool in enterprises bankruptcy prediction
Aneta Ptak-Chmielewska

Last financial crisis affected the SMEs sector in different countries at different levels and strength. SMEs represent the backbone of the economy of every country and need a prediction model easily adaptable to their characteristics. Since the Altman's Z-Score model a large number of statistical bankruptcy prediction studies were written using the traditional methods. Recent studies in this area focus on more advanced methods. Predicting bankruptcies in Poland have been of interest since 1990s. First models were based on small samples and mainly on linear discriminant analysis. Later on newer statistical techniques were applied and the sizes of the data samples were bigger. The dataset used in this paper consists of 806 SMEs, including 311 bankrupt and 495 non-bankrupt SMEs from the Polish market. The FSs data covered the period 2008−2010 and bankruptcies 2009−2012. As analysis tool the Support Vector Machines (SVM) was used. SVM are based on the concept of decision planes that define decision boundaries. The classic example of a separation like discriminant analysis is a linear classifier that separates a set of objects into their respective groups with a line. Most classification tasks, however, are not that simple, and often more complex structures are needed in order to correctly classify new objects. Hypothesis verified is following: Multidimensional discrimination like SVM gives more precise predictions of bankruptcy comparing to simple linear discrimination.

3 - Time-Varying Analysis of the Liquidation Risk of the UK SMEs
Ba Hung Nguyen, Galina Andreeva, Nam Huynh

We analyze the risk of going into liquidation of the UK SMEs from 2004 onwards using several survival models. A large sample of 103,115 UK SMEs is used with company fixed characteristics (Legal Form, Industry Code, ...), time-varying financial ratios (Solvency Ratios, Profitability Ratios, ...), and time-varying macroeconomic indicators (Unemployment Rate, Real Exchange Rate, Net Domestic Credit, . . .). We compare continuous-time and discrete-time survival models, and for the latter one, we experiment with several specifications of baseline hazard. We comment on the performance of different models in different time periods: prior to the credit crisis of 2008, during the crisis, and following it. The presentation also explores how the effects of predictors on liquidation risk change over time, their interactions, the problem of missing values and ways to address it. The results are timely and relevant given the current political uncertainty posed by Brexit and the recent slowdown in small business growth - according to the UK National Federation of Self Employed & Small Businesses (FSB), there was a fall of 27,000 SMEs in 2017-2018, following a long period of sustainable growth.

■ WC-29

Wednesday, 12:30-14:00 - C118

Governance Analytics 1

Stream: Governance Analytics
Invited session
Chair: *Cathal MacSwiney Brugha*

1 - How do country characteristics at the economic, regulatory and cultural levels affect cross-border e-commerce sales in Europe? An empirical study.
Zohreh Khooban, Nevin Mutlu, Ton de Kok, Sarah Gelper

One of the priorities of the European Commission is to establish a Single Digital Market in Europe, where customers can seamlessly make online purchases from other countries. Despite the Commission's efforts, cross-border sales constituted only 15% of Europe's total online sales in 2014. The objective of this study is to develop insights that aid retailers and policy-makers in decision-making towards establishing a Single Digital Market in Europe. Towards that end, we conduct an empirical analysis using a unique data-set on the European consumers' cross-border shopping behavior. Specifically, we examine how country characteristics at the economic, regulatory, and cultural levels moderate the effects of individual-level drivers of cross-border online sales.

2 - Governance Analytics and Operational Research
Cathal MacSwiney Brugha

Governance Analytics brings an analytical approach to governance. This includes: 1 Processes for analysis, design, implementation, and use. 2 Problem-Solving Methods for getting capacities, bringing in capabilities, making contributions, and giving to community. 3 Types of Governing of administrations, operations, development, and management. 4. Governance Approaches: rule, care, respond, and serve. Operational Research can bring care into the governance process of designing solutions to society's major challenges, that challenge the scope of routine administration of rules. We suggest the operational research community should not be dependent on getting permission from administrators to consider solutions to major problems and opportunities. We can independently design such solutions, using our operational research conference as a Forum, and test this idea for the first time at EURO2019. The major project chosen for this test is about how to capture wind energy (mainly from the Atlantic) and heat energy (mainly from the south of Europe) and grid it across Europe. Whenever this is achieved it will realise immense potential benefits both environmentally and economically. The questions are can renewable energy academics and industry experts combine their capabilities to develop a feasible contribution, that reduces global warming, carbon gases emissions, and over-use of oil and gas? Could it be adopted by the European Parliament being elected in May? Could it be implemented?

3 - A new method for optimal proportional representation
Kaj Holmberg

In a democratic proportional election system, it is vital that the mandates in the parliament are allocated as proportionally as possible to the number of votes the parties got in the election. We formulate an optimization model for allocation of seats in a parliament so as to minimize the disproportionality. By applying separable programming techniques, we obtain an easily solvable problem, and present a method for solving it optimally. The obtained solution is thus the feasible solution that has the minimal disproportionality (with the measure chosen), in contrast to the heuristic procedures used in many countries. We apply the approach to real life data from the last three elections in Sweden, and show that the result is better, ie more proportional, than what was obtained with the adjusted odd number rule, which is presently used. A natural suggestion would be to use our method instead.

We also consider the issue about constituencies, and suggest a procedure, based on the same kind of optimization problem, for allocating mandates in the constituencies, without changing the overall allocation with respect to parties. In our approach, the numbers of mandates for the constituencies are based on the number of votes given, not on estimated numbers of inhabitants. This removes the need for fixed and equalization mandates, and also makes the question about sizes of the constituencies less important.

■ WC-30

Wednesday, 12:30-14:00 - C007

Forecasting

Stream: Forecasting and Time Series Prediction
Invited session
Chair: *Pirmin Schwarenthorer*

1 - Macroeconomic Trend Integration in Business Forecasting
Pirmin Schwarenthorer, Alfred Taudes, Johannes Hunschofsky

Traditionally, companies forecast based on company internal historical time-series data and qualitative signals from the market. In times of volatile markets, this leads to a myopic view that is not capable of anticipating demand shocks or trading cycles. This paper presents a forecasting method that matches macroeconomic trends with microeconomic performance indicators to obtain a more robust data basis. After calculating the rates of change of monthly sales data, a correlation analysis with predictable macroeconomic trend indicators like the purchasing manager index is conducted in order to accomplish a business forecast based on leading indicators. The resulting forecasts can be used for tactical and strategic supply chain decisions reaching from the extension of supplier basis and human resource decisions to investments in production facilities. Using practical examples of an US based global player in the oil and gas industry as well as a market leader in the formwork industry it is shown that the application of this method leads to better investment decisions both in case the trend points upwards and in case the trend points downwards. In either case, companies applying this kind of forecasting method are vested with a competitive advantage compared to companies who conduct yearly forecasts based on internal data only.

2 - Forecasting Turning Points of Business Conditions by Quantitative Text Analysis
Nariyasu Yamasawa

For policy makers and business persons, knowing the turning points of business cycle is important. We present a procedure for deciding turning points of Business Conditions by quantitative text analysis. We use text data of "Japanese Economy Watcher Survey". It has been released since January 2000 by the Cabinet office in Japan. This statistics contain huge text data which show the reason of respondents' judgement about business conditions. We extract words from 190 thousands sentences and construct time series data for every word by counting appearance rate every month. We apply machine learning technique for estimating business conditions. Teacher data is the data which indicate 1 if the period is expansion phase of business conditions and 0 if the period is in the shrinking phase. We applied several classification algorithms such as Naive Bayes method to text data to classify business conditions. And it was better performance than existing method for forecasting turning points.

3 - Forecasting Intermittent Demand Using Machine Learning
Rui Lopes, Gonçalo Figueira, Mário Amorim Lopes

Demand timeseries forecast is a topic of active research in Operations Research with a strong impact for practitioners in many industries. The forecasting algorithms used rely heavily on traditional statistical methods, with some digressions into Machine Learning addressing intermittent demand, although restricted to neural networks. These typically use a combination of endogenous data with two engineered features: i) the size of the last zero demand interval (LDI); and ii) the cumulative periods with zero demand (CZD). The use of these features is mutually exclusive, with researchers opting for one or another.

Our work compares the performance of each of these features with Support Vector Machines, Random Forests, and Gradient Boosting, on a diverse set of lumpy and intermittent demand patterns (according to the Syntetos-Boylan classification). The forecasts are analysed using the normalised root mean squared error (NRMSE) and the mean arctangent absolute error (MAAPE). The results vary significantly using the two error metrics and the different algorithms. For SVR the features are detrimental. For the ensemble methods MAAPE indicates that a better performance is obtained using the CZD, while NMRSE shows better performance using the LDI, and in many cases only the endogenous variables. Moreover, only Random Forests had a significant improvement in the average MAAPE, showing a threshold for the average demand interval above which it is clearly beneficial to use the CZD.

■ WC-31

Wednesday, 12:30-14:00 - G108

Simulation of Emergency Departments

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Laura Boyle*

1 - A Simulation-based Optimization approach for the hospital Emergency Department management
Massimo Roma, Tommaso Giovannelli, Stefano Lucidi, Massimo Maurici, Mauro Messedaglia, Luca Paulon, Doriana Zanna

The task of an Emergency Department is providing healthcare services for people who need urgent medical treatments. Since the services delivered by an ED are time critical, the main issue to be considered concerns the response time. Unfortunately, the well known and increasing problem of the overcrowding tends to enlarge the waiting times, endangering the life of critical patients. Insufficient staff, shortcomings of the structures, request of nonurgent treatments, unavailability of hospital beds are among the possible causes. Besides treatment delays, overcrowding leads to reduced quality of the services, excessive number of patients in the ED, many patients which leave without being seen. In this work, we propose the adoption of the Simulation-based Optimization approach for studying the patient flows through an ED, aiming at determining the ED settings, mainly the human resources and the buffer capacity of the holding area for different clinical pathways, so that some proper Key Performance Indicators are optimized. To this aim, first a Discrete Event Simulation model is constructed reproducing the patient flows from the arrival to the ED until the discharge. To achieve a reliable model, real data from the ED of an Italian hospital are used. As second stage, the DES model is combined with a Derivative-Free Optimization method, which enables to determine the optimal settings. This approach provides an effective decision support system in the management of an ED.

2 - The application of a case manager approach in emergency departments
Lien Vanbrabant, Kris Braekers, Katrien Ramaekers

Emergency departments (EDs) are continuously exploring opportunities to improve their efficiency. One of the main bottlenecks in an ED are physicians. Physicians have a major impact on ED performance as they have multiple consultations with each patient. In addition, they are a costly resource, resulting in multiple patients being assigned to the same physician simultaneously to make full use of their capacity. Multitasking has the advantage of reducing idle time. However, patient switching costs, i.e., consultation setup times, increase with the number of patients per physician because of cognitive limitations. Multitasking is beneficial as long as the reduction in idle time by assigning an additional patient to a physician exceeds the increase in patient switching costs. In order to maximise physician productivity, the optimal number of patients per physician should be determined. In this regard, the application of a case manager approach with limited caseloads is proposed. It involves the use of dedicated physicians, limiting the number of patients simultaneously assigned to a single physician, and determining appropriate priority rules for assigning patients to physicians. The potential of applying a case manager approach to improve ED performance is tested by use of a discrete-event simulation model based on a real-life case study. The results show that overall ED performance may be improved, but the effect size depends on the specific case manager setting.

3 - Improving emergency department patient flow using discrete event simulation with Coxian phase-type distributions
Laura Boyle, Adele H Marshall, Mark Mackay

Hospital emergency departments (EDs) operate under significant pressure worldwide. Overcrowding is a frequent occurrence, caused by a combination of high presentation numbers, insufficient resources within EDs, and long delays in the transfer or discharge of patients due to a lack of availability of hospital beds and care in the community. Frequent breaches of time-based performance targets are reported in a wide range of national healthcare systems, including the UK and Australia, which are the particular focus of this work. These issues are projected to intensify, as ED numbers continue to climb - in Australia, at a rate of 3.7% annually.

This research presents a novel application of discrete event simulation (DES) to model a major ED in Adelaide, Australia utilising the combined benefits of DES and Coxian phase-type distributions to model emergency department patient flow. DES is used to capture ED behaviour over time as an evolution of stochastic variables, and to perform scenario experimentation for process improvement. Coxian phase-type regression models are used to estimate covariate-specific length of stay in the system. The results from identifying and simulating various improvement scenarios will be presented.

This study forms part of a larger conceptual modelling framework for developing generalisable models, which aims to promote model reuse, implementation, and allow direct comparison between EDs.

4 - Modelling policy options for the provision of dementia care by a local authority
Brian Dangerfield, Sally Brailsford

The incidence of dementia is absorbing considerable health care resources and it is unsurprising that a considerable scientific literature has emerged on this topic. The modelling community has contributed to this endeavour with many studies conducted by clinical and epidemiological scientists mainly with the objective of predicting prevalence and consequential costs at a national level. However, it seems that relatively few studies have been undertaken by the OR modelling community. The research undertaken for this paper addressed some policy options available to a London Borough and were set in the context of a climate of financial austerity. A system dynamics simulation model was used to explore various issues, examples being the support for informal carers, the effects of charging for home care support and capacity restrictions on a special clinic which can assist in the effective diagnosis of the condition. The study stands as a testament to the benefits of OR modelling for public health support at the local level.

■ WC-33

Wednesday, 12:30-14:00 - Q005

Economic modelling and game theory III

Stream: Dynamics and Games
Invited session
Chair: Jussi Uusivuori

1 - Signaling Supplier Capability using Cost of Quality Analysis: Payoff Maximization v. Inequality Aversion
Dipankar Bose, Sumit Sarkar

In this paper, we develop a buyer-supplier signaling game to distinguish between high and low capability supplier in terms of quality improvement given the supplier type is not known to the buyer. Using supplier's investment for quality improvement as a signal, this paper contributes to the extant literature by demonstrating the effect of the cost of quality (COQ) on the outcome of the signaling game, where COQ is a function of investment. We characterize the perfect Bayesian equilibria (PBE) of the game when the buyer is payoff maximizer, as well as when he is inequality averse. If the buyer is a payoff maximizer, he can choose appropriate price to rule out pooling PBE. Conversely, existence of pooling PBE cannot be ruled out when the buyer is inequality averse. However, if the buyer is inequality averse, the investment and consequently the quality is higher, which in turn increases the supply chain surplus. We also conduct a numerical analysis to examine the sensitivity of the likelihood of existence of separating PBE for changes in capability gap between the two types of suppliers and buyer's valuation of quality, along with various COQ parameters, such as sampling plan and penalty for defective items. Our numerical analysis provides some guidelines for the buyer in terms of the magnitude of penalty as well as the appropriate nature of investment and sampling plan that is to be followed by the supplier.

2 - Core formation and profit allocation of horizontal cooperation in covering location problems: a game theoretical approach.
Roghayyeh Alizadeh, Tatsushi Nishi

Location costs and covering profit gained from locating facilities in covering location problems consist a large fraction of strategic decisions in supply chain optimization process. In this research, we have studied different incentives that encourage the players to collaborate with each other to maximize their profit. Various possible combinations of coalitions have also studied and the related characteristic functions for each has been obtained using the mathematical model. To be able to find the best coalition structure for each player and share the profit fairly among the players of optimum coalition structure, a method has been proposed and some computational experiments have been conducted to evaluate the efficiency of the proposed method and obtain managerial and strategic insights.

3 - Generalized two-fund monetary separation and asset pricing model in a mean-lower partial moment framework
Dipankar Mondal, Selvaraju Natarajan

Two-fund monetary separation (TFMS), is a very important property in the literature of portfolio management. In a mean-lower partial moment (MLPM) framework, the separation is obtained when the target rate is equal to either the risk-free rate or the expected return. The existence of other targets, if any, that permit the separation has remained an open question for three decades. This paper solves this open problem analytically. We develop a generalized form of target returns that guarantees the separation in the MLPM framework. Furthermore, using the separation, a generalized MLPM capital asset pricing model (CAPM) is developed. The new pricing model generalizes the earlier models developed by Bawa and Lindenberg (1977) and Lee and Rao (1988). The classical mean-variance CAPM can also be seen as a special case of the new model.

4 - On the extraction of a non-renewable resource with amenity value
Jussi Uusivuori

This paper deals with the question of finding a solution to a dynamic extraction problem of an exhaustible resource. In part we build on the classical models by Ramsey (1928), Cass (1965) and Koopmans (1965) who analyzed closed-economy growth models with intertemporally maximizing, infinitely-lived dynasties exhibiting an assumed population growth rate. In the discrete-time model presented here utility is obtained from periodic consumption levels produced with the use of a fixed-rate capital and the depletion of the resource, as well as from periodic amenity values of the natural resource stock. Thus, in the present model the resource contributes to both consumptive and amenity utilities. In the present model, generations are interconnected by intergenerational altruism. Furthermore, we integrate into the analysis the impacts of ownership structure by assuming that the resource is a common-pool resource whose both spatial and dynamic allocation is designed by a benevolent social planner. This feature allows us to incorporate intra-generational inequity issues along with studying inter-generational properties. We show that the optimal allocation of the resource becomes dependent on population growth, wealth level, wealth inequality, ecological vulnerability of the resource and rivalry on the amenity value of the resource.

■ WC-34

Wednesday, 12:30-14:00 - Q006

Modelling and Optimisation in Disaster Relief

Stream: Mathematical Modelling
Invited session
Chair: Georg Gutjahr

1 - Relief Distribution in the First Days of the Kerala Flood Disaster
Georg Gutjahr, Haritha Viswanath, Sachin Das

The Kerala flood in the summer of 2018 was the most severe flood in South India in almost a century. Over 5 million people lost their homes and many of them were affected with fever and cold. After the flood, over 1 million people had to stay in relief camps for several months. In total, 3200 relief camps were supplied from 26 emergency response centers for an extended time period. Call centers played a major role in rescuing people in the first days of the flood. In total, the call centers handled 35000 calls during the first 3 days. One would expect that such calls enable an estimation of the flooded regions and the available links. A stochastic model based on the calls might be useful to guide the relief distribution during the first days of the disaster when reliable information is still sparse.

In this work, we consider an approach for simultaneously fitting a statistical model of the spatial distribution of demand and accessibility, and at the same time for making the first necessary decisions on the organization of the supply. The statistical model uses a spatial point process based on the origins of the incoming calls. Topological features such as altitudes are taken into account. As to the decision-making part, we consider a multi-commodity model dealing with food, water, clothing, vaccination, sanitary items, tarpaulins, mosquito nets, and medicine. For the numerical solution, heuristics are applied.

2 - Configuration of Humanitarian Networks subject to Post-Disaster Attacks
Christos Zikopoulos, Xenofon Taouktsis

Our work studies the issue of the configuration of humanitarian supply networks in areas affected by a natural or man-made disaster. It aims to provide decision-making tools for the organization and management of Humanitarian Aid teams, which are responsible for meeting the needs of these areas. By modeling the problem of the distribution of humanitarian aid as a typical "Traveling Salesman Problem", we examine the alternative options for the selection of the location of the distribution center. During the determination of the most appropriate location, it should be taken into account that there is a risk of additional disasters defined as "attacks". The attacks change the characteristics of the initial network by canceling, temporarily or permanently, some of its edges, and therefore the determination of the distribution center location should include the consideration of the robustness of the solution. Some concepts of the network theory are implemented and appropriate centrality measures are calculated to address the problem more effectively. Correlation and dependency tests of critical network characteristics are performed in order to quantify the relationship between the initial state of affected areas with post-attack characteristics. The goal is to reach to a decision that favors the smooth flow of humanitarian aid despite potential problems in critical nodes (regions), preserving the operating efficiency of the Humanitarian Aid teams.

3 - Integrating mitigation, response and recovery operations for efficient earthquake management

Betul Coban, Maria Paola Scaparra

The O.R. literature on disaster operation management (DOM) is very vast, as evidenced by the numerous review papers. Traditionally, there are four DOM stages: mitigation, preparedness, response, and recovery. Most existing papers have addressed problems in each DOM stage separately, whereas only a few studies have considered integrating operations in different stages. Integrated models should therefore be developed to capture these interdependencies and fully optimise disaster operations. In this paper, we propose an integrated model that combines mitigation, response and recovery operations for an earthquake case. Optimising investments in mitigation measures has a clear impact on the efficiency of post-earthquake operations. For example, structural mitigation measures can be used to increase road resilience to earthquakes. Road conditions (operational or not) directly affect the delivery of time-sensitive services and relief supplies after an earthquake, as well as the evacuation of people from the affected areas. This study focuses on prioritizing pre-earthquake mitigation actions considering direct structural-related losses and the indirect cost associated with travel delays and reduced accessibility to critical emergency facilities. The proposed model aims at identifying optimal mitigation strategies so as to maximize the efficiency of response operations and minimise the time and cost of recovery operations after a disaster. Preliminary results are presented.

4 - Determining the optimum size and pricing strategy for a cellulosic bio-refinery contracting with multiple biomass producers

Hayri Önal, Sinem Tokcaer, Ozgur Ozpeynirci

In 2005, the US government introduced the Renewable Fuel Standard (RFS), which requires blending biofuels with oil-based fuels with special emphasis on cellulosic biofuels obtained from energy crops. Since inception of RFS, production of cellulosic biofuels at commercial scale has been stalling due to high conversion costs, low oil prices, limited availability of agricultural resources, absence of biomass market, and perennial nature of energy crops. We envision that the cellulosic biofuel industry can become reality only if bio-refineries guarantee a steady flow of biomass at a reasonably low price, while biomass producers receive guaranteed returns over a medium time horizon. Contracting between biomass producers and bio-refineries may establish such a sustainable system. Two important and closely related managerial decisions are the scale of bio-refining operation and the price of biomass. Given that refinery and biomass producers are independent decision makers operating in a hierarchical order, we formulate the problem as a non-linear bilevel optimization model. We use optimization theory and a systematic search algorithm to find the optimal solution. We apply the model to a hypothetical cellulosic bio-refinery to be located in the U.S. Midwest surrounded by numerous farm units each operated by a profit-maximizing and risk-averse agent. We present the empirical results along with different scenarios on the conditions affecting the optimal refinery size and biomass price.

■ WC-35

Wednesday, 12:30-14:00 - Q009

Hospital logistics

Stream: Healthcare Logistics
Invited session
Chair: Fermin Mallor

1 - A multi-item inventory distribution problem with heterogeneous fleet : a case study in a hospital

Adelaide Cerveira, Agostinho Agra, Cristina Requejo

A multi-item inventory distribution problem with heterogeneous fleet motivated by a practical case study occurring in the logistics operations of a hospital is considered. There is a single warehouse which supplies several nursing wards. The distribution of medical products is done by two teams of workers using different kinds of available vehicles. The is a heterogeneous fleet with vehicles having different capacities and different structures required to be used in specific nursing wards. The goal is to define a weekly distribution plan ensuring a balanced workload of both working teams and satisfying all the required constraints (inventory capacities, safety stock levels, vehicle capacities, etc.) that minimize the total number of visits to locations. A mathematical formulation is presented. This is a NP-hard problem hardly solved to optimality within a reasonable amount of time, and more so for real size instances, with hundreds to few thousand products. To circumvent this issue, a matheuristic is proposed and the computational results are discussed.

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2 - Integrating hospital inventory management and distribution scheduling

Maria Madalena Lima, Inês Marques

Healthcare costs have been gradually increasing in developed countries over the past years, leading to an emerging interest in improving logistic activities in hospitals, which constitute a large portion of the expenses. Furthermore, there is a growing pressure to improve performance and deliver healthcare more effectively and efficiently. Hospitals are responsible for a large amount of items of different kinds and often with expiry dates. Inventory management is a difficult task, where ordering, distribution and consumption must be achieved and coordinated between the different services, maintaining obsolescence levels and waste to a minimum. Although it is significantly studied in industrial environments, material logistics is less developed in the healthcare setting. The complexity lies on deciding when and how much to order of each medical supply, organizing and scheduling transportation and deliveries, as well as on dealing with capacity and human resource constraints in an environment such as healthcare, where stock-outs are not allowed. With the goal of reducing stocks and decreasing the variability in the workload of deliveries, an optimization model for inventory management and deliveries scheduling is proposed. The model is then applied to the case of a hospital in Portugal, where a central warehouse serves numerous care units, with deliveries spaced-out through the week.

3 - An interactive computer simulation model to learn Intensive Care Unit management

Daniel García de Vicuña, Laida Esparza Artanga, Fermin Mallor

Interactive computer simulation creates a virtual world in which users can explore and participate in critical management issues facing a range of industries and organizations. Although its use is usual in areas as defense, aviation, stock market . . . , no such software has been developed to learn about the complexity of the Intensive Care Unit (ICU) management. This paper introduces an ICU interactive simulator which enables training and experimentation with patient admission and discharge decisions and their impact on the ICU performance. The mathematical model is a discrete event simulation model in which patient arrivals occur according to a known schedule for those coming from surgeries or randomly for emergency patients. Users can manage the simulated ICU by deciding every day which patients will be discharged and which programmed surgeries will be suspended due to a lack of beds. Moreover, when patients arrive at ICU the user must decide about their admission or diversion. At any time of the simulation the user can consult patients' health status through a complete clinical report. In fact, the screen of the simulator imitates and provides the same information that is displayed and recorded by the dedicated software Metavision' which creates a totally realistic ICU environment. Other main features of the simulator will be presented. For instance, its flexibility to create different working environments defined by the size of the ICU, the occupancy ratio...

4 - A hybrid heuristic algorithm that mimics the human rationale to solve the physician scheduling problem
Pedro Mateo, Marta Cildoz, Fermin Mallor

This work addresses the physician scheduling problem. This is a very difficult practical problem that has to consider many different types of constraints (demand, workload, ergonomic, etc.), and the achievement of multiple goals related with the fairness of the schedule among all physicians. The problem can be mathematically modeled as an integer linear programming problem but for large instances it cannot be solved effectively. In this work, a constructive heuristic algorithm which mimics the human scheduling process followed by the manager at the hospital is developed. The algorithm works in several stages. It builds in each stage a more complete scheduling, by sequentially fixing the days of work, the periods of the day in which physicians work and the type of shifts. The rationale is to fix first the characteristics that are considered more important in the fairness assessment of a schedule. As the construction of the schedule progresses the scheduling of new shift characteristics and specific shifts is more constrained and then more difficult to achieve the complete fairness (and even the feasibility). The heuristic combines the use of the constructive phase of a Greedy Randomized Adaptive Search Procedure (GRASP) with sequences of small mixed integer linear programming problems. The application of the algorithm has been tested in a real case in which it is necessary to schedule the 43 physicians of an Emergency Department of a Spanish hospital.

■ WC-36

Wednesday, 12:30-14:00 - Q010

Heuristics for Vehicle Routing Problems II

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: *Rosa G. González-Ramírez*

1 - A Hybrid Algorithm for the Fuel Delivery Problem with Unloading Considerations
Konstantinos Androutsopoulos, Dimitris Boukosis

This paper introduces a new Vehicle Routing Problem (VRP) that is encountered in the fuel distribution industry. The proposed problem determines the routes for a heterogeneous fleet of multi-compartment vehicles for servicing a set of orders including multiple different fuel. The criterion used for the emerging Multi-compartment VRP is the minimization of the distance under the following constraints: i) each vehicle can be used multiple times, ii) the loading factor must be above a given lower bound and iii) the delivery sequence of orders must comply with a given unloading precedence constraint. The last constraint stems from the safety requirement encountered in this industry to distribute the payload weight uniformly on the axes of the truck. A hybrid heuristic algorithm was developed for solving the emerging routing problem. It is based on the cooperation between GRASP and Large Neighborhood Search (LNS) techniques. The algorithm involves a series of GRASP iterations that involve the following sequence of steps: i) a new semi-randomised insertion route building procedure that determines the initial feasible solution, ii) a set of route improvement procedures that aim to improve the loading factor of the initial routes, and iii) a LNS routine that iteratively destroys and rebuilds part of the solution. The computational performance of the proposed solution approach has been tested on a series of real life test instances.

2 - Districting design for a parcel company with multiple demand scenarios
Rosa G. González-Ramírez, Neale Smith, José-Fernando Camacho-Vallejo, Carla Vairetti, Samuel Moisés Nucamendi Guillén

Districting or territorial design, geographic demand zone segmentation and customer clustering are rather common and well-studied problems within literature of design and planning of logistic and supply chain networks, mainly focused on distribution/collection supply chain subsystem. In this research we address a logistics districting design for a parcel company whose operations consists of picking up and delivering packages along a service region. The region is divided into districts, so that each district is served by a single vehicle. We propose a strategy based on multiple demand scenarios. A mathematical model is formulated in which three criteria are optimized: minimize the maximum average workload content of a district, minimize the exceeding workload content in each district, and designing districts of compact shape. The solution methodology proposed is a hybrid heuristic algorithm that takes elements of GRASP and Tabu Search. Numerical experimentation is performed, for which a set of instances was generated, based on real data provided by a parcel company.

3 - A rich two-echelon electric vehicle routing problem with satellite versatility
Dario Pacino, Satya Malladi, Jonas Christensen, Allan Larsen

This talk studies a Two-Echelon Electric Vehicle Routing problem, aimed at enabling urban electromobility of freight. The first echelon consists of routing trucks carrying goods to parking lots (satellite location) from depots. The truck will stay at the parking lot for an amount of time and thereafter continues on its route. The second echelon concerns the routing of smaller electric vehicles, originating at the satellite locations, to serve all customers. At the beginning of the day, a number of electric vehicles are available at each satellite location. In this work we do not require the small vehicles to return to the same satellite at the end of the day, and they can visit any satellite to get replenished with additional goods en-route. However, they can only be replenished at a satellite if there is a truck at the time. This requires continuous synchronization between the first echelon routing and the second echelon routing. Along with acting as a source of goods for the electric vehicles, the trucks will also provide spare batteries and battery swapping services giving the electric vehicles a driving range boost. However, regular charging stations are also available for en-route charging. In this talk, we wish to formally describe this problem, how it differs from most two-echelon VRPs and present preliminary results.

■ WC-37

Wednesday, 12:30-14:00 - Q011

Advances in Game Theory and Economics

Stream: Mathematical Models in Macro- and Microeconomics
Invited session
Chair: *Alexander Vasin*
Chair: *Gerhard-Wilhelm Weber*

1 - On the Use of Monte Carlo Tree Search to Play Carcassonne
Fred Valdez Ameneyro, Edgar Galvan, Ángel Fernando Kuri Morales

Monte Carlo Tree Search (MCTS), is a decision-making algorithm, which uses a best-first search technique to build a decision tree. MCTS can be applied to any domain where simulation and statistical modelling can be used to predict outcomes, such as behavioural modelling, decision support, to mention a few examples. The positive impact of using MCTS in games can be understood by considering its impressive results achieved on the game of Go, where MCTS has been able to beat professional players, something unthinkable a few years ago, given the intractability of its decision space along with the need of problem-specific knowledge. The use of MCTS has been mainly used in games with perfect information and deterministic scenarios (e.g., equal probability of playing with either a black or white stone for the game of Go). In this work, we propose the use MCTS to play Carcassonne, which is a perfect information and non-deterministic board game, given that the tiles available to play the game are drawn randomly. The game is highly difficult to be played against any Artificial Intelligence technique because of the aforementioned non-deterministic nature of the game, a lack of uniform frequency for each type of tile available in the game as well as the size of its estimated State-space complexity (5*1040) and its Game-tree Complexity (8*10194). We show how MCTS with automated heuristic to reward statistical simulations can be a good method to play the game of Carcassonne.

2 - Using Monitoring Efforts to Reduce Sabotaging in Contests

Yossi Hadad, Baruch Keren, Yizhaq Minchuk

This paper considers a contest with three stages with both sabotage and monitoring efforts that aim to reduce sabotage. In the first stage, the regulator sets his monitoring efforts for each contestant. In the second stage, each contestant determines his sabotaging efforts, based on the monitoring efforts that were imposed by the regulator. In the third stage, each contestant determines his productive efforts in the contest. The results supply a justification to exert monitoring efforts because these efforts may benefit both the contestants and the regulator (a win-win situation). The paper also defines the conditions where exerting monitoring efforts would be worthwhile.

3 - Application of Game Theory in Vehicle Routing Problems

Dana Figurová, Zuzana Čičková, Matej Zagiba

In general, Game Theory provides tools to analyze a wide range of conflict decision situations which predisposes its utilization across multiple application areas. One of these areas is logistics. This contribution is dedicated to one of the versions of the Vehicle Routing Problem. We will present new models in order to describe the situation of customer service from central depots. Players are the owners of individual depots who need to satisfy the requirements of their customers. Each player in this game uses different type of vehicle to satisfy customer's demands. Players can act independently or they can cooperate with other players, while the factor determining cooperative behavior is the reduction their shipping costs. On the one hand, the coalition's savings come from the more advantageous customer assignments to the depot within the coalition or on the other hand, savings come from simultaneous use of the vehicle that can be repeatedly reloaded at another depot (not the starting one). Therefore, players in coalitions can achieve the bigger benefits than when acting independently. There are several ways to redistribute these benefits between the players in individual coalitions. At the end of this presentation, we will introduce some known approaches of quantifying the surplus of redistribution which are based on the strength of the player in the coalition.

4 - On the optimal choice of candidates for a tax inspectorate

Alexander Vasin, Pavel Nikolaev

We consider a model of the tax audit and the problem of selecting candidates for the tax inspectorate taking into account their heterogeneous professional training. It is assumed that at the disposal of the inspection organizer there are trustees who always check correctly, but the costs of conducting inspections by them are very high. Also, the organizer may involve for inspections an unlimited number of rational inspectors who are ready to take bribes, if it is profitable for them. Each inspector is characterized by an inspection accuracy, which determines the average share of the income he reveals when checking the tax evader. Also, the inspector is characterized by an alternative salary, which can be received at another place of work upon dismissal from the tax inspectorate. The organizer of the inspection knows these characteristics of all candidates. The organizer's strategy includes probabilities of inspections and revisions depending on the tax declarations, the salaries of inspectors, and the rule for selecting candidates for inspection. The paper solves the problem of finding the optimal strategy that ensures the fair payment of tax by taxpayers at minimum costs for the inspection organization. The results allow generalization for other government agencies performing law enforcement functions.

■ WC-38

Wednesday, 12:30-14:00 - Q012

Preferences and Pairwise Comparisons 2

Stream: Multiple Criteria Decision Aid
Invited session
Chair: Michele Fedrizzi

1 - Quantification of incompleteness in the PC method

Konrad Kułakowski, Jacek Szybowski, Anna Prusak

Besides consistency, the completeness of information is one of the key factors influencing data quality. In the case of the pairwise comparisons (PC) method, much space in the literature is devoted to the quantitative analysis of this first idea, while the second issue has not been properly studied. The presented paper is an attempt to bridge this gap. During the research, two important factors related to the incompleteness of PC matrices have been identified. The are the number of missing pairwise comparisons and their arrangement within the matrix. Based on that four easy-to-calculate incompleteness indices have been developed. During the series of Montecarlo experiments, the properties of these indices have been examined. In particular it was demonstrated that both the incompleteness and inconsistency of data almost equally contribute to the sensitivity of the PC matrix.

2 - Extracting pairwise comparisons information from textual data using opinion mining

Sajid Siraj

This research focuses on extracting and understanding phrases from textual data that contain pairwise comparisons related information. With the emergence of big data, there is a huge amount of decision-making related information available which is still untapped due to the fact that this information is stored in unstructured formats like free text, audio recordings, etc. With the help of opinion mining tools and techniques, our aim is to construct a (complete or incomplete) pairwise comparison matrix from narratives collected from online reviews and blogs. We will present our preliminary findings from the data collected for common decision problems like buying a car or comparing smartphones. We consider this a novel area of research with a number of useful applications in prescriptive and descriptive research related to decision making.

3 - A multiplicative best-worst method for multi-criteria decision making

Matteo Brunelli, Jafar Rezaei

The best-worst method (BWM) for multi-criteria decision analysis has gained popularity since its recent introduction. One advantage of the BWM is that it allows the elicitation of the priority vector from a properly chosen subset of all possible pairwise comparisons. In our research we shall examine this method from a more mathematical perspective and propose an alternative formulation. In particular, with the new formulation a different metric is used as objective function. While seemingly more complex, it can be shown that instead the new metric is (i) more suitable for a problem where preferences are expressed as ratios and (ii) makes the entire optimization problem easier to be solved. In fact, with its new formulation the optimization problem can be equivalently formulated as a linear program. We will also show that, besides having these advantages, this new approach retains all the features of the original BWM as, for instance, the possibility of estimating inconsistency and of being extended to generate interval-valued weights.

4 - The tournament index of inconsistency
Jacek Szybowski

Pairwise comparisons are commonly used in decision making. The results of such comparisons are expressed in numbers, which may come from different sets. The most popular domains are real numbers, real positive numbers or their finite subsets. The bigger range of numbers we take into consideration, the more detailed comparisons can be, but, on the other hand, the judgments become more difficult for a decision maker. This is the reason why, in certain circumstances, one takes only three possible values into consideration (1, 0.5 or 0, corresponding to win, draw and loss), when carrying out a judge.

This attempt has been recently used as a part of The Characteristic Objects Method (COMET). It is also widely applied in sport, for example in football leagues. To obtain the final ranking one takes into consideration the points scored by teams in matches. A natural expectation is that the team A classified above the team B had defeated its weaker rival and the teams C and D classified under the same heading had drawn. However, in real life it may be the other way round, which implies inconsistency.

This simple observation leads us to the definition of a tournament index of inconsistency for pairwise comparison matrices with elements taken from only three element set (trinary PCMs). In the presentation we introduce this index,compare it with the index recently defined by Kulakowski and suggest a natural transformation of the set of all PCMs into the set of trinary ones.

■ WC-39

Wednesday, 12:30-14:00 - Q014

Personnel scheduling

Stream: Timetabling
Invited session
Chair: *Pieter Smet*
Chair: *Greet Vanden Berghe*

1 - Workforce Scheduling in Post-Disaster Situations
Niels-Fabian Baur, Julia Rieck

Every year, several disasters occur for which appropriate response must be planned and implemented. Even in highly developed countries in Europe, not all disasters can be prevented. Experiences show that there is usually a great willingness to voluntarily help in emergency and post-disaster situations. The consideration of volunteers with their specific skills in performing activities, that are present in a project, can minimize material damages as well as personal injury. Floods are, for example, one of the most frequent disasters in Europe. In the event of flooding, activities (e.g. construction of dams, removal of mud and debris) must be carried out by helpers with different skills (e.g. driving licenses, physical fitness) as well as special machinery. We present a dynamic problem with scarce resources, time constraints and variable activity durations (e.g. depending on the number of available helpers and their skills) for workforce scheduling in case of a disaster. Several different objective functions are examined, the main objective is to minimize the overall project duration to ensure that the project ends as soon as possible. The problem is being modelled by a mathematical formulation and problem instances are solved with GAMS and CPLEX. The perspective is to develop a fast heuristic approach that can be embedded into a decision support system to solve the problem in a dynamic environment where volunteers come and go regularly.

2 - Proving optimality for every International Nurse Rostering Competition problem using column generation
Isaac Cleland, Andrew J Mason, Michael O'Sullivan

The First International Nurse Rostering Competition (INRC) was held in 2010 to find new approaches to solve staff rostering problems. The INRC problem instances are difficult to solve, and since the competition has finished, multiple research groups have found better-quality solutions than those previously found. However, not every solution had been proven to be optimal. We have found and proven optimality for solutions to the 30 hardest INRC problem instances and in doing so have found multiple better-quality solutions than have been found previously. All these solutions have been found and proven optimal within a 4-hour time window. We have achieved this through a series of improvements to Genie++, a nested column generation algorithm for solving staff rostering problems. These improvements include new branching techniques, an objective function perturbation, a new dominance technique, and a constraint aggregation technique. These techniques are all applicable to a broad range of staff rostering problems as they are not specific to the INRC.

3 - Automatic weight adjustment for the nurse rostering problem
Elín Björk Böðvarsdóttir, Pieter Smet, Greet Vanden Berghe

Despite the continuous progression in nurse rostering research over the years, only a few hospitals are benefitting from these advancements in their every-day scheduling. One of the reasons for the limited use of automatic scheduling in practice is the absence of the experience-based intuition that planners apply when manually generating schedules. The relative importance of different objectives reported by the planners does not always coincide with their day-to-day decisions. Furthermore, the planners' decisions are not consistent, as their intuition perceives the quality of a schedule differently for different cases. Therefore, an automatic scheduling approach might require several iterations of adjusting the weights of different objectives to obtain a solution that meets the needs of the planners. We propose a multi-phase method to automatize these iterations, where an initial phase produces a solution, and the subsequent phases analyze the quality of the solution and seek to improve it based on various KPIs. We have defined these KPIs based on a dialog with practitioners and their intuition regarding schedule quality. Consequently, this method generates final weights based on the planners' insights, rather than their perception of the relative importance of different objectives. Automatizing this process should result in a less resource intensive scheduling and thereby act as an encouragement for practitioners to incorporate the research in their everyday scheduling.

■ WC-40

Wednesday, 12:30-14:00 - Q015

Integrated Routing Problems II

Stream: Vehicle Routing and Logistics Optimization II
Invited session
Chair: *Igor Averbakh*

1 - A Simultaneous Pickup and Delivery Routing Problem with Time Windows in the Sustainable Food Supply Chains
Mahdi Farshchi, Sedef Meral, Ferda Can Çetinkaya

The aim of our study is transportation planning in perishable food supply chains. We formulate a mixed-integer linear model as the vehicle routing problem with simultaneous pickup and delivery, and soft time windows for perishable products (VRPSPD-STW-P). The objective is the minimization of the total costs, consisting of variable transportation costs, vehicle-related fixed costs, quality degradation costs, and time-window violation costs. Moreover, we propose heuristic and meta-heuristic algorithms in the methodology to solve the VRPSPD-STW-P. Our methodology comprises two phases: obtaining initial solutions in the first phase and improving the solutions by a genetic algorithm in the second phase. In these phases, we first employ a method based on clustering of nodes for the vehicles and different routing heuristics to generate the best routes for the vehicles; that is solving the problem as an m-travelling salesperson problem with simultaneous pickup and delivery (m-TSPSPD). The solution of the m-TSPSPD is checked for feasibility taking into account the vehicle capacities and tour lengths; the feasible routes are then the solutions for the vehicle routing problem with simultaneous pickup and delivery (VRPSPD); finally, VRPSPD solution is evaluated considering the time window and quality constraints (VRPSPD-STW-P). Our solution methodology yields promising solutions in much less computational time when compared with solutions generated by the exact solution procedures.

2 - A Two-Phase Branch and Cut Algorithm for the Capacitated Location Routing Problem
Theocharis Metzidakis, Panagiotis Repoussis, Manolis Kritikos, George Ioannou

In this work we present a Branch and Cut solution framework for the Capacitated Location Routing Problem (CLRP). The CLRP is a challenging combinatorial optimization problem with many practical applications. Given a set of candidate depot locations as well as a set of geographically scattered customers with known demands, the goal is to determine the locations and design least cost routes so as to service the customers using a fixed fleet of homogeneous capacitated vehicles. We propose an iterative two-phase Branch-and-Cut algorithm. The main idea is to initially solve the Facility Location Problem followed by the corresponding Multi Depot Vehicle Routing Problem. At each iteration we restrict accordingly the solution space. Using benchmark datasets taken from the literature, various computational experiments are reported. Preliminary results are promising.

3 - A probabilistic method for a pickup and delivery problem with time window uncertainty
Péter Györgyi, Tamas Kis

We consider dynamic pickup and delivery problems with time window uncertainties as defined recently by Srour et al. In that model there is a transportation service provider that gets calls from customers with exact pickup and drop-off locations, but with inaccurate estimations of the time windows for the transportations. The time windows of the service requests become known with certainty only after a second call from the customers, shortly before the service may start.

We present a new algorithm that may help transportation service providers that operate in the above context to find better vehicle tours. Our method is based on estimating the expected operational costs, where missing a customer request is heavily penalized, and the other cost component is the total deadhead cost (operating empty while going to the next pickup location or to the depot). The novelty of our approach is that we do not generate scenarios, and we solve only a single minimum cost flow problem at each decision point.

Our method outperforms the earlier methods in terms of average total cost on several classes of instances with various characteristics, while it is inferior only in a well-characterized setting. Another advantage of our method is its low running time, the entire simulation run with 100 customers and 40 vehicles was less than a second.

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4 - The Probabilistic Uncapacitated Open Vehicle Routing Location Problem
Igor Averbakh, Wei Yu

Suppose that several mobile service units are located at a base station (depot) in a transportation network. On any day, the nodes of the network may generate calls for service independently with known probabilities. The calls are centrally allocated to the service units who then visit the allocated customers on shortest open tours, that is, for each service unit, the way back to the depot from the last served customer is not counted towards the length of the tour. It is required to find an optimal location for the depot to minimize the expected travel distance. We obtain bounds on the approximation ratios for two simple and fast heuristics for the problem on a general network. For the problem on a tree, we present an exact algorithm which is polynomial if the number of service units is fixed.

■ WC-41

Wednesday, 12:30-14:00 - Q013

Autonomous vehicles

Stream: Public Transportation I
Invited session
Chair: Marie Schmidt

1 - Integrating autonomous vehicles to design innovative public transport services in rural areas
Joachim R. Daduna

The technical development of autonomous vehicles for road transport has sufficiently advanced in recent years. With the legal framework for a use in public road networks previously existing restrictions are omitted now. A key area for innovative applications is the improvement of public transport in rural areas, which for the most part currently allows only a very limited supply for economic reasons due to the existing demand structures. This does not mean, however, that existing supply structures will be eliminated. These will continue to be significant in regional transport, while the services associated with autonomous vehicles will be primarily demand-driven and of importance at the local level. The focus here is on the use of robotaxis, car- and ride-sharing and local (on-demand) line-based services with minibuses. In order to give (potential) customers information about the offered services, it is necessary to design new tools that ensure sufficiently wide and precise information in real time. In addition, routing within multimodal networks must be possible, including flexible services, to provide information especially concerning multimodal trips, which are particularly evident in regional public transport. At the same time, the prerequisites for demand-based services at the local level must be developed and implemented. This includes communication between suppliers and customers as well as the planning and the operational monitoring and control.

2 - Rolling horizon heuristic with optimality guarantee for an autonomous vehicle scheduling problem
Johann Hartleb, Marie Schmidt, Markus Friedrich

A scenario in the near future might be that public transport is partly operated by autonomous vehicles. Then, the amount of required vehicles can be reduced by vehicle scheduling. In contrast to vehicle scheduling problems for timetabled public transport, autonomous vehicle trips can be demanded essentially at every time between different locations yielding large input data. Due to this structure we propose a minimum flow formulation on a time-space network for this problem. In order to solve large-scale instances we suggest using a rolling horizon heuristic which splits the network flow problem into tractable parts. Furthermore, we provide an optimality guarantee for the rolling horizon heuristic for certain parameters of the heuristic. With this, we are able to find optimal vehicle schedules for a travel demand model of the Stuttgart region with more than 100 million variables.

3 - Assessing the performance of drone-based and ground-based parcel delivery systems
Thomas Kirschstein

Drones are regarded as one of the technological innovations which may trigger a revolutionary reshaping of logistics. This is mainly caused by the prospect of quick, cheap, and flexible deliveries which complies with current trends in the transport industry particularly in last-mile and city logistics. Therefore, a lot of pilot projects have been launched in order to exploit the potentials of drones in logistics applications. However, it is noway sure to which extent drones can exploit the promised economic and ecologic potentials in large-scaled logistical systems. To assess the overall potential of drone logistics, drone-based and ground-based parcel delivery systems have to be compared with regard to energy demand, flexibility, and transportation cost. In this talk the strategic advantages of conventional parcel delivery systems with conventional vehicles, electric vehicles, and drones are evaluated for varying scenarios. A special focus is put on effects of environmental conditions on the energy demands of all modes of transportation. For drones particularly, weight, wind conditions, and hovering time turn out to be crucial for the delivery system's overall performance.

4 - Sequence and Speed Optimization for Delivery Robots
Stefan Schaudt, Tolga Bektas

Autonomous delivery robots are a new technology used for last-mile deliveries, which run on pavements, and are capable of transporting one good at a time. The advantage of using a robot is that the delivery can commence upon receiving a request, which helps to enhance customer satisfaction. This talk will describe a joint sequencing and speed optimization problem to serve a given set of customers within pre-specified time intervals by using a fleet of autonomous robots. The aim is to minimize the energy needed, which is modeled as a quadratic function of speed. The speed in turn is assumed to be controllable and can therefore be optimized. A branch-and-price algorithm is developed for the problem, in which the pricing step entails solving a resource constraint elementary shortest path problem, and where the optimal speed on each leg of a given tour can be calculated in polynomial time. Tests were carried out with the branch-and-price algorithm and a speed discretized formulation of the problem on randomly generated instances employing a grid layout. The latter was only able to optimally solve instances of up to 15 customers, whereas the former was capable of solving instances of up to 30 customers to proven optimality under a common time limit of one hour.

■ WC-42

Wednesday, 12:30-14:00 - Q113

Freight transportation and logistics II

Stream: Transportation
Invited session
Chair: Arne Heinold

1 - Hinterland intermodal transport routing as a port community system added value offer: a Colombian case study
Adriana Moros, Rene Amaya, Guisselle Garcia, Stefan Voss

In the context of port communities, one of the most common used technological developments are the Port Community Systems (PCS). A PCS can be defined as an inter-organizational system for promoting commercial services and information exchange between the port to their customers and a variety of stakeholders, such as forwarders, carriers, importers, exporters, customs, among others. The typical services of a PCS are information exchange, electronic exchange of Customs declarations and responses, control, tracking and tracing of the goods, and processing of maritime and other statistics. However, it has been argued the need to evolve the existing PCS into a renewed version, more suitable to the novel requirements posed by both developed and emerging economies, and incorporating the surge of new technologies. Such renovation should care for integrating new value-added services to the aforementioned typical PCS services offer. Therefore, we propose a new hinterland intermodal routing service to be included to the regular PCS functionality. Such service takes as input the results of an optimization model, which delivers a sustainable and cost-effective intermodal transport network. The proposed hinterland intermodal routing service could help mitigate the environmental impact of the Colombian hinterland transport and the national transportation costs, increasing the nation's competitiveness and sustainability through a value-added service.

2 - Taking into account temperatures in wine shipping decisions: model, risk indices, and applications
Alejandro Mac Cawley, Max Garafulic

Most of the wine is transported in dry containers, exposing it to the prevailing temperature conditions during its maritime transport, which can affect its quality. Transport decisions are mostly based on costs, with the least cost route being preferred usually, without considering the potential temperature risks. In this study, we develop a decision support model for the shipping route selection problem, taking into account the temperature risk during maritime transport. To achieve this, we construct a model that considers the internal container temperature information obtained from 167 shipments of wine and determines the correlation with the external temperature. We also present a set of temperature risk indices, which allows us to assess the risk to the wine shipment for a specific route. We validate this model by applying it to a group of routes and show that the lowest cost route can have the highest risk for wine quality. Hence, a more expensive and less risky alternative route should be considered.

3 - Environmentally oriented routing in intermodal rail/road freight transportation networks
Arne Heinold, Frank Meisel

Recent studies show that intermodal rail/road freight transportation is often less harmful to the environment than road-only transportation. However, several factors influence the environmental impact of intermodal transportation networks, such as vehicle type, traction type or payload utilization. In addition, some customers are more cautious about their environmental impact than others, which forces transportation companies to offer transport solutions for different customer requirements. In this study, we address the problem of environmentally oriented routing in intermodal rail/road freight transportation networks. The problem is modeled as a service network design problem and can be easily complemented by other modes of transportation. Particular attention is paid to the integration of environmentally driven customer requirements that form hard constraints on the maximal amount of emissions per order, and the necessary integration of emission-allocation methods within the optimization model. We present solutions where the model determines an optimal allocation scheme for each order as well as solutions where the same allocation method is applied to all orders. Our experiments show that the allocation scheme has a strong impact on the feasibility of solutions.

■ WC-44

Wednesday, 12:30-14:00 - Q115

Revenue Management Applications

Stream: Revenue Management in Production and Logistics
Invited session
Chair: Martina Megasari

1 - Integrating Revenue Management and Order Acceptance in a Two-Machine Flow Shop
Sebastian Spindler, Claudius Steinhardt

Order acceptance decisions can significantly increase the revenue of a manufacturer and many research scientists have addressed this problem in the context of scheduling in the past. The order acceptance and two-machine flow shop scheduling problem deals with the acceptance of a set of jobs which are then assigned to a two-machine flow shop schedule. Each accepted job yields a specific revenue and needs to be scheduled on both machines with a given processing time. If the due date of a job is exceeded, penalty costs occur. The question to be answered is: Which jobs should be accepted or rejected such that the total profit, i.e. the overall revenue minus the total delay costs, is maximized? In this talk, we investigate a variant of the problem at hand where orders arrive stochastically over time and we apply approaches from the revenue management literature as well as different approximation algorithms for its solution. In an extensive simulation study, our methods are compared to simple heuristics and a number of adaptions of already existing solution methods.

2 - Social Learning from Online Reviews with Product Choice
Stefano Vaccari, Costis Maglaras, Marco Scarsini

Product choice when consumers engage in social learning has significant implications on learning outcomes and on the information accumulation rate. In many practical settings, consumers decide which product to buy, if any, among several possible alternatives. The quality of these products may be unknown to consumers, but online platforms provide product reviews so that, as time goes by, customers accumulate information about products' quality. This paper studies a model where consumers estimate the quality of products from like/dislike reviews and make choices using a multinomial logit model. We explore the impact of choice on the learning outcome, and using a large market (fluid model) approximation, we study how choice and product parameters affect learning speed and derive some intuition on the primitives that matter the most. Finally, we address the following product display problem: assuming that consumers suffer some search cost to go down the list of displayed products, which order of products should the platform use to speed up learning and purchases? Using the fluid approximation, we formulate this problem as an optimal control problem in continuous time. We characterize the optimal solution in the case the platform knows the quality of products. In the case where the platform itself learns the quality of products over time, we analyze the regret associated to different heuristics explore/exploit ranking policies with respect to the full information benchmark.

3 - An Approximate Dynamic Programming Approach to Queueing Admission Control Problems
Saied Samiedaluie, Dan Zhang

We study a classical queueing control problem with multiple classes of customers. The queue is a loss system; i.e., arriving customers are rejected if all servers are busy. When a server is available, the decision is whether to admit an arriving customer and collect a lump-sum revenue. We model this problem as a continuous-time infinite-horizon dynamic program and propose approximate linear programming methods to solve the problem under three approximation architectures: affine, finite affine, and separable piecewise linear. For both affine and finite affine approximations, we derive reduced formulations which are equivalent to the original approximate linear programs (ALPs), but are much more compact in size and therefore can be efficiently solved. We also propose a column generation algorithm to solve the separable piecewise linear approximation. Our numerical results show that the affine and separable piecewise linear approximations demonstrate similar performance both in terms of the quality of the bounds and the policy performance when the number of servers are large. Both approximations are inferior to the finite affine approximation when the number of servers is very large and/or the load on the system is high. Therefore, the finite affine approximation emerges as a competitive and efficient approximation for the problem. We believe it is potentially useful for a wide variety of queueing control problems.

4 - Machine Learning Based Forecasting and Hotel Revenue Optimization with Channel Management
Martina Megasari, Guiming Lin, Xavier Callens, Bernard Rannou

This paper presents a complete flow of hotel revenue management system (RMS) from demand forecasting, revenue optimizing to final evaluation. The hotel big data platform of Amadeus, one of the biggest global distribution systems (GDSs), has been leveraged to perform experiments using industrial data. In hotel revenue management (RM), most research mainly focuses on price discrimination, and scarce work is conducted on non-pricing techniques, especially channel management. We propose a novel theory by optimizing the inventory allocation on channel level using expected marginal revenue (EMR) algorithm. In demand forecasting, this paper has experimented and compared the performance between classical and machine learning (ML) based model. It shows that ML outperforms classical one with 37% lower in terms of Mean Absolute Percentage Error (MAPE) and that on top of the existing typical RM strategy running in the hotel platform, the new approach can achieve an extra gain up to 2.13% for further revenue improvement.

■ WC-45

Wednesday, 12:30-14:00 - Q117

Electric Vehicles

Stream: Green Logistics
Invited session
Chair: *Maximilian Schiffer*
Chair: *Gerhard Hiermann*
Chair: *Yiran Cheng*

1 - An optimization framework for a light electric vehicle sharing system
Selin Ataç, Michel Bierlaire, Nikola Obrenovic

The vehicle sharing systems (VSSs) are becoming more and more popular due to both financial and environmental effects. On the other hand, they face many challenges, such as inventory management of the vehicles and parking spots, imbalance of the vehicles, pricing strategies, and demand forecasting. If these are not addressed properly, the system experiences a significant loss of customers and therefore revenue. Although efficient methods to solve these problems are well-studied in the literature, with the introduction of a new type of light electric vehicles (LEV) some of the methodologies became inapplicable. The rebalancing methods constructed for conventional VSSs (bike and car sharing systems) are not convenient for the LEVs since a LEV is not as small as a bicycle, making it unsuitable for rebalancing with a truck, and has only one seat, preventing the transport of staff, which is common in car rebalancing operations. Also, demand forecasting becomes a challenging task since LEVs are allowed to be parked on any designated spot in the city. LEVs also serve for a higher portion of the population since they do not require a driving license. Moreover, as the vehicle is electric there should exist a fleet of workers who replace the batteries. This work provides a new framework for the LEV sharing system management from a wider perspective by addressing the components and the relations between these components. The proposed framework is also related to conventional VSSs.

2 - Evaluating electric mobility in urban service logistics
Satya Malladi, David Ramirez Marti, Jonas Christensen, Allan Larsen, Dario Pacino

Electric mobility is characterized by a clean and noiseless drive alongside a limited driving range. It serves the purpose of urban logistics almost perfectly catering to short distances in city centers and to the onus to maintain air quality and reduce noise pollution in densely populated areas. A general urban service logistics problem with a mixed fleet including electric vehicles, compatibility specification between customers' requests and drivers' skills, and time windows is considered. In our formulation, we propose an upgrade to the energy consumption model to account for auxiliary loads during the drive. We develop a novel adaptive large neighborhood search algorithm to solve the operational problem on each day.

To understand the influence of factors such as temperature, time window tightness, spread of customers, etc. on the total cost of fleet ownership, we perform a simulation analysis on two real case studies from Copenhagen. In the first case study, we look into electrician routing for a construction firm, MT Hojgaard, using a mixed fleet of vehicles (both electric and non-electric), while in the other, we work with Region Hovedstaten to efficiently plan the pick-up logistics of temperature-controlled, time-sensitive transport of blood samples from clinics to a testing laboratory using a mixed fleet of electric vehicles.

This work is aimed towards developing decision-making tools that enable a smooth transition to electric mobility.

3 - Using an enhanced artificial bee colony algorithm to solve the Electric Vehicle Routing Problem
Yiran Cheng, Wai Yuen Szeto

With the deterioration of the environment, people start replacing fuel vehicles by electric vehicles in logistic activities. Electric vehicle routing problem is gaining more and more attention from the researchers. This paper introduces the heterogeneous electric vehicle routing problem with time windows, partial charging, and piecewise linear charging functions. The available heterogeneous vehicle types differ in their load capacities, battery sizes, and charging functions. The charging amount is considered to be a decision variable and the charging process is approximated as a piecewise linear function. Unlike the literature, this variant simultaneously considers the following: (1) time windows for the customers, (2) time windows at both recharging stations and the depot, (3) heterogeneous vehicle fleet, (4) partial charging, (5) current-battery-level-dependent recharging time/cost, and (6) a non-constant charging rate. An enhanced artificial bee colony algorithm is adopted to solve the problem. Several operators for partial charging, time-window infeasibility repairs, for inserting a recharging station, and partial charging amount adjustment are proposed. Numerical studies showed that with the proposed operators, the enhanced artificial bee colony algorithm can outperform CPLEX in terms of both CPU time and solution quality in all the tested instances, and the introduction of the novel operators can improve solution quality.

■ WC-46

Wednesday, 12:30-14:00 - L243

OR in Industry

Stream: OR in Industry and Software for OR (contributed)
Contributed session
Chair: Guillerme Duvillié

1 - Stochastic Modelling and Simulation for Industrial High-Rate Aerosol-Assisted Chemical Vapour Deposition
Pedro Ivo de Oliveira Filho, Panagiota Angeli, Claire J. Carmalt, Eric S. Fraga

Solar technology is a pivotal option for clean energy production. Reducing the cost of solar modules is, therefore, a key element to increase the potential of such a solution. Solar cells are based on Transparent and Conductive Oxide (TCO) films, which can be produced by the Aerosol-Assisted Chemical Vapour Deposition (AACVD) process. Concisely, the AACVD process is based on sequential stages. Firstly, aerosol is generated from a solution containing TCO precursors. It is then transported to a heated chamber, where the solvent evaporates and the desired film is formed. Computational modelling is crucial for the AACVD process design and scale-up. The difficulty in modelling the film formation is due to uncertainties associated with predicting the mechanisms and rates of chemical reactions, both in gas and solid phases, adsorption and desorption. Our objective is, therefore, to stochastically model the film formation. We run a series of simulations to assess the uncertainties and compare the film growth rate with experimental data from the literature. The results inform us how to optimise the input to the heated chamber, which is linked to the aerosol generation and transport models. Although our results may agree well with the limited data available on film thickness, it should be recognised that the uncertainties in the model parameters and mechanisms may compensate each other, leading to favourable model performance. Future research includes the study of such a relationship.

2 - Coordinating inventory management and transportation decisions in a third-party logistics distribution network
Dimitris Zissis, Alena Puchkova, Vaggelis Giannikas, Wenrong Lu

We consider a distribution network that integrates supply, storage, and transportation activities, seeking to examine how coordinating inventory and transportation decisions affects performance. We hypothesise that via the coordination of inventory and transportation decisions, the distribution network could succeed substantial cost savings and improved service levels. We develop an optimisation model that supports replenishment decisions in order to deliver products on time and meet customer demand, utilising an existing warehouse network and a fleet of vehicles. Furthermore, we consider the distribution network as a dynamic environment in which several conditions can change affecting the cost structures, demand and time constraints, thus the optimal replenishment decisions. Our results indicate that the computation time is reasonable for the requirements of this business problem. As a result, the proposed model is flexible to determine new strategies, allowing immediate actions. The proposed work is evaluated through a case study in a third-part logistics distribution network in China.

3 - Solving Hamiltonian Cycle problems using Boolean Satisfiability
Andrew Johnson

A classic NP-complete problem is finding a cycle visiting all nodes in a graph exactly once. This paper details the techniques used by the author to solve 614 of the 1001 graphs of Flinders Hamiltonian Cycle Problem Challenge Set, varying from 96 to 9528 nodes. Once of the powerful techniques given here is the author's very efficient general reduction of the Hamiltonian Cycle Problem (HCP) to Boolean Satisfiability (SAT) converting any Hamiltonian Cycle problem with n vertices and m directed edges to a SAT problem with approximately n.log2(m) variables and 2m.(log2(n)+1) clauses. This reduction is significantly smaller and more efficient than any other published reductions, which are impractical for more than a few hundred nodes. For each graph the SAT problem was submitted to a SAT solver and any solution converted back to the HCP domain. Generating certain additional constraints with additional clauses or variables for the SAT problem actually improved the solve time with existing SAT solvers and so helped to solve more graphs. Graph manipulations allowed still more graphs to be solved. The HCP to SAT reduction may have other uses for scheduling and permutation type problems.

4 - A Branch and Price algorithm for the Wafer-to-Wafer Integration Problem
Guillerme Duvillié, Trivikram Dokka, Yves Crama, Frits Spieksma

We consider the Wafer-to-Wafer integration problem described as follows. We are given m sets of n wafers (a wafer being a disc of silicon on which dies are engraved). We aim at gathering wafers into stacks of m layers such that each stack contains exactly one wafer of each set and such that each wafer belongs to exactly one stack. The output is thus a set of n disjoint stacks covering every wafer of the instance. However the engraving process is not a perfect one, and each wafer contains several faulty dies whose location is known. When superimposing two wafers, the position l of the stack is unfaulty iff the dies at position l in all the wafers composing the stack are unfaulty. The cost of a solution is given by the overall number of faulty positions in the n stacks. The objective is then to minimize the cost. This problem arises in IC industry during the manufacturing of 3-dimensional processors. Several integer linear programs have been proposed to tackle this problem. The most efficient formulation turns out to have an exponential number of variables (a binary variable for each possible stack) and thus can only be used to solve small instances. We propose a branch-and-price algorithm that allows the resolution of larger instances.

■ WC-47

Wednesday, 12:30-14:00 - L247

Nonlinear Programming and Applications

Stream: Continuous and Black Box Optimization
Invited session
Chair: Andrea Cristofari

1 - An algorithm model for continuously differentiable multiobjective optimization problems
Stefano Lucidi, Guido Cocchi, Giampaolo Liuzzi, Marco Sciandrone

In this work, we propose an algorithm model for multiobjective optimization problems. All the objective functions are assumed to be continuously differentiable. A distinguishing feature of the proposed method is that of not scalarizing the objective functions but rather of trying to build an approximation of the Pareto front. The algorithm iteratively improves a temporary list of non dominated solutions. At every iteration, this list is updated by performing suitable multiobjective linesearch techniques starting from the points of the old list. These linesearch techniques are performed along directions which must satisfy mild descent properties with respect some or all the objective functions. The proposed multiobjective linesearch techniques and the required properties of the search directions are able to guarantee that sequence of lists produced by the algorithm model globally converges towards a set of Pareto stationary points. Finally we report the results of a preliminary numerical experience where we have compared the computational behavior of a particular implementation of the described algorithm model on a set of test problems with the ones of algorithms based on approaches previously proposed in literature.

2 - A stochastic network equilibrium model for electric power markets with uncertain demand
Massimo Pappalardo, Mauro Passacantando, Fabio Raciti

We use the theory of stochastic variational inequalities to develop a network equilibrium model of the whole supply chain of electricity markets: power generation, supply, transmission, and consumption. In particular, we take into account the case where the market demand functions are not exactly known but are affected by some kind of uncertainty. A discretization and truncation procedure is used to numerically solve the stochastic variational inequality model. Monotonicity properties of the operator are investigated and the affine case is analyzed in detail. Finally, numerical experiments show the impact of different probability densities of the random variables on the approximated solutions and the scalability of the proposed numerical method for real-world sized problems.

3 - An almost cyclic 2-coordinate descent method for minimization problems with one linear equality constraint
Andrea Cristofari

A block decomposition method is proposed for the minimization of a non-convex continuously differentiable function subject to one linear equality constraint and simple bounds on the variables. In the proposed method, the working set is computed according to an almost cyclic strategy that considers the distance of each variable from its nearest bound. Since our working set selection rule does not use first-order information, we do not need to compute the whole gradient of the objective function during the algorithm, leading to high efficiency when the problem dimension is large and the partial derivatives of the objective function are cheap. Under an appropriate assumption on the level set, global convergence to stationary points is established by using first-order directions and different line search strategies. Finally, numerical experiments on convex and non-convex problems show the effectiveness of the proposed method.

■ WC-48

Wednesday, 12:30-14:00 - L248

OR Applications in Industry 1

Stream: OR Applications in Industry
Invited session
Chair: *Lukas Bach*
Chair: *Geir Hasle*
Chair: *Benjamin Ivorra*

1 - A Decision Support System for a Door-to-Door Transportation of Mixed Normal and Disabled People
Mauro Dell'Amico, Roberto Baldacci, Marco Antonio Boschetti

We propose a Decision Support System for door-to-door transportation services which includes possible disabled people that travel with wheelchair or accompanying persons. Since the transportation are mainly performed in the inner town, we consider a wide set of complex traffic restrictions, such as: (i) access limitations depending on the vehicle type and emission level, (ii) turning restrictions, (iii) travel times depending by the traffic conditions, (iv) the possibility of performing U-turn for some vehicles, (v) the need to pickup and drop-off customers at the right or left side of the road, etc. The basic underlying optimization problem is known in the literature as the Dial-A-Ride Problem. We model the problem as a complex pickup and delivery vehicle routing problem, with the above restrictions and constraints ensuring the quality of service. These include specific time windows for the pickup or the drop-off, limits in the waiting time at a stop, and maximum ride time constraints. The objective is to satisfy all transportation requests minimizing a weighted function of the cost and of the service level. We propose an effective heuristic algorithm designed and tested on a large bed of real-world instances. The algorithm is able to define a complete solution or to add a new transportation request to an existing solution keeping the schedules of the requests already planned. The DSS is currently in use by a number of public and private transportation companies.

2 - Analyzing the value of information sharing in a Norwegian grocery supply chain
Peter Schütz, Ebba Celius, Madeleine Goldsack, Heidi Dreyer

We analyze the value of information sharing between a wholesaler and a transport company in a Norwegian grocery supply chain. Of particular interest is the question how large the benefits of sharing future demand information are and how they can be realized. The planning problem of distributing groceries to the retail stores is represented by two set covering problems, one for each company. These models select predefined routes in order to minimize the costs of satisfying retailer demand. The wholesaler's model can in this setting be considered as some sort of tactical planning model, defining the feasible decision space for the transport company's operational model. By changing the planning horizon of the models and the amount of information transferred from the wholesaler to the transport company, we are able to evaluate the potential savings resulting from sharing future demand information. Our results indicate that information sharing per se does not necessarily lead to cost savings, but that additional flexibility in the planning process might be required in order to realize its full benefits.

3 - Machine Learning for the Surveillance of the Norwegian Power Market
Gavin Bell

The surveillance of power markets to catch and discourage market manipulation and insider trading is attracting increasing focus among regulators, market operators and power market actors. Traditional surveillance methods are built around the construction of rule-based alerts, that flag when pre-defined events or patterns occur. However, rule-based systems tend to generate large volumes of alerts which are difficult to prioritize and interpret. Rule-based alert systems can also struggle to detect new manipulation strategies for which they have not been designed. Together with NVE, the Norwegian power market regulator, we are applying novel machine learning methods as an alternative approach to alert generation for surveillance of the Norwegian power market. Here we report on some preliminary results of our work and analysis, with a focus on alerts for sealed-bid double auction (e.g. day-ahead) electricity markets.

4 - SOSMAR - A software for studying the evolution and the cleaning process of Oil Spills in Open Sea
Benjamin Ivorra, Susana Gomez, Angel Manuel Ramos

The main goal of this work is to present a software, called SOSMAR, used to simulate the evolution of oil spots in the open sea and the effect of a skimmer ship pumping oil out from the spots. The concentration of the pollutant is subject to the effects of wave, wind and sea currents, evaporation, emulsion, dispersion, diffusion, and the pumping action of a skimmer (i.e., cleaning) ship that follows a pre-assigned trajectory. This implies that this software is based on an Eulerian mathematical model of the advection-diffusion-reaction type. Furthermore, we consider second order discretization schemes with nonlinear flux limiters for the numerical implementation. Then, considering a global optimization approach, we design optimal trajectories for skimmer ships to clean and recover the oil. Next, we validate the ability of this software to forecast the fate of the oil, by comparing our results with satellite images and real data. Then, we create a synthetic study case based on real data, and we show that following optimal trajectories greatly improves the amount of oil recovered at the whole area of study.

■ WC-49

Wednesday, 12:30-14:00 - L249

Dynamical Models in Sustainable Development II

Stream: Dynamical Models in Sustainable Development
Invited session
Chair: *Pierre Kunsch*

1 - Optimization of water artificial circulation for eutrophication control
Lino J. Alvarez-Vazquez, Francisco J. Fernandez, Aurea Martinez

This work deals with artificial recirculation as a shallow water aeration technique to reduce eutrophication problems in waterbodies.

First we introduce a well-posed mathematical formulation of the environmental problem in terms of a control/state constrained optimal control problem of nonlinear partial differential equations, coupling the modified three-dimensional Navier-Stokes equations (including a Smagorinsky turbulence term) with the convection heat transfer equation (with mixed convective/radiative boundary conditions) and with the eutrophication model (considering Michaelis-Menten kinetics for the interactions between nutrients, phytoplankton, zooplankton, dissolved oxygen and organic detritus), where the state constraints are related to water quality, the control constraints translate technological limitations, and the objective function represents energy saving.

Then, we present a complete numerical algorithm for the resolution of the full problem, based on a combination of the method of characteristics and the finite element method for the numerical resolution of the state systems, and an interior-point method for solving the discretized optimization problem. Finally, using the free scientific software FreeFem++ interfaced with the open source code IPOPT, we show some numerical results for a realistic computational example posed in a reservoir.

(This work was supported by MINECO/FEDER (Spain) project MTM2015-65570-P)

2 - Controlling heavy metals concentration in shallow water by phytoremediation methods
Aurea Martinez, Lino J. Alvarez-Vazquez, Rodriguez Carmen, Miguel E. Vazquez-Mendez, Miguel A. Vilar

We optimize different issues related to phytoremediation methods for heavy metals removal from shallow water by means of a combination of mathematical modelling, optimal control of partial differential equations and numerical optimization. In particular, we try to determine the minimal quantity of algae to be used in heavy metals remediation processes, and also their location.

So, we introduce a novel 2D mathematical system of nonlinear partial differential equations modelling the concentrations of heavy metals, nutrients and algae in large bodies of shallow water. Then, we formulate an optimal control problem related to the optimization of the phytoremediation process, where the state is given by the solution of this nonlinear system, the constraints represent geopolitical/technological restrictions, and the cost function to be minimized measures heavy metals concentration inside a sensitive region to be protected.

Finally, we propose two different algorithms for computing the numerical solution of the constrained optimal control problem, and we show several numerical results for a real-world scenario in estuary Ria de Vigo (NW Spain).

(The authors thank the support from project MTM2015-65570-P of MINECO/FEDER (Spain))

3 - Diffusion of green innovations: The organizational setup of pilot projects and its influence on consumer perceptions
Sandra Kretschmer, Veronika Grimm, Simon Mehl

The successful transformation and decarbonisation of energy systems relies critically on the market deployment of innovative and sustainable technologies. In this regard, the application of pilot-, test- and demonstration-projects (PTD) is the most prominent tool to promote the diffusion of green technologies. As technology diffusion is heavily dependent on the number, individual attributes and beliefs of potential adopters, it is crucial to understand how a PTD-environment can shape individual product perceptions and hence diffusion processes. In this paper, we analyse the influence of a PTD's organizational setup on the technology perceptions of potential participants and their evaluation of product characteristics. By varying the information on a PTD's organizational setup in a survey experiment among a selected sample of potential PTD-first movers, we gather first experimental evidence for the effect of different PTD-settings on the perception of energy-related technologies. We find that the organizational setup has a significant impact on a product's perceived contribution to the energy transition, cost-reduction potential and environmental friendliness. In particular, full organizational cooperation between government, university and industry seems to consistently improve perceptions compared to a partial setup. Our findings provide policy-makers with a more ample foundation on how PTDs should be designed in order to successfully transfer technologies to the market.

4 - PROSE-GDSS: Approaching sustainability with System Dynamics and MCDA
Pierre Kunsch, Alessio Ishizaka, Sylia Hanana

Complex sustainability problems require new decision tools to assist multiple stakeholders in defining robust and flexible policies in a long-term perspective. The author proposes a policy-making tool called PROSE-GDSS (standing for 'Profile Ranking with Order Statistics Evaluations - Group Decision Support System'). This multi-criteria/multiple stakeholders procedure combines MCDA,voting theory and System Dynamics. The purpose is to provide a interactive and transparent platform to stakeholders designing sustainable policies.

■ WC-50

Wednesday, 12:30-14:00 - Mason Hayes & Curran

Understanding the practice of Problem Structuring Methods - II

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: *Alberto Paucar-Caceres*

1 - A new approach for developing the Swedish Armed Forces
Jan Frelin

The Swedish Armed Forces approached the Swedish Defence Research Agency (FOI) to review their methods for capability development.

The current methodology for development in the armed forces is an adaption of Systems Analysis, with some competition from Concept Development frameworks. In addition to these two frameworks, it was decided to also study the feasibility of using military estimate methods or Mingers framework for multimethodology for capability development.

We found that all frameworks had pros and cons in relation to military capability development, and that none of the framworks were deemed sufficient to cover all types of problems. The two options considered to adress this situation was to develop a new framework, or to allow different development teams to use different works. In the end, the latter approach was chosen.

2 - Measuring and Managing Complexity in Viable Systems: A Reconsideration of Beer's Notion of Variety
Ayham Fattoum

Variety, as defined by the viable system mode (VSM), may be the only measure of complexity in soft OR. Often, complexity and variety are used interchangeably, and are rarely considered in light of actuality and potentiality of the studied complexity. This paper suggests that variety may be impractical during emergencies when rapid decisions are needed. Therefore, this paper offers an in-depth analysis of variety and complexity using empirical data collected from two simulated responses to disasters in the UK. The paper proposes that complexity as the actual and experienced states should be prioritised during emergencies. To aid decision-making, this paper theorises a novel model that categorises complexity and its generators according to two criteria. First, is their relation to the organisation, that is either internal or external. Second, is their impact on the operations, that is supportive or problematic. These new models and definitions are then embedded within VSM to guide decision-makers at different levels. This paper informs the soft OR community with a new interpretation of complexity that is more compatible with social systems, operationally effective, and can be adopted by many soft OR methodologies.

3 - A Survey of Problem Structuring Methods and Multi-Methodology Applications in Latin America
Maria Alejandra Castellini, Melany Ángeles Segarra Marinetti, Alberto Paucar-Caceres

This paper takes stock of Problem Structuring Methods (PSM) and Multimethodoy (MM) applications published in Latin America between 1980-2018. By surveying articles published in six Managements sciences/Operational research (MS/OR) and Systems Thinking and Practice (STP journals), we seek to build a picture of PSM and MM practice, detect influences and explore trends of soft OR developments in the region. We surveyed PSM articles in abstracts from four MS/OR Journals: European Journal of Operational Research, Journal of Operational Research Society, Omega and International Transactions in Operations Research; and from the STP field: Systemic Research & Behavioral Science, and Systemic Practice and Action Research. The total of sixty (60) papers were: Brazil (32); Colombia (10); Venezuela, Peru, Chile and Mexico (4 each), Bolivia and Argentina (1 each). Regarding themes of application: MM applications (15); Systems Thinking (10); Viable System Model (7); Soft System Methodology (5); System Dynamics (4), and other topics between 1 and 3 articles. Journals with most papers were SPAR (19), EJOR (15), and JORS (11). Although the number of publications are small, these results seem to indicate that PSM has becoming part of the MS/OR practice in LA. This has been driven by co-authorships publications schemes between LA and EU researchers. Overall, PSM publications seems to follow the same cyclical trends of fashion experienced in European MS/OR practice.

4 - Using Maturana's Ontology of the Observer to enrich Checkland's Soft Systems Methodology
Alberto Paucar-Caceres, Bruno Jerardino-Wiesenborn, Alejandro Ochoa Arias

The paper explores the prospect of combining two systemic methodologies into a theoretical framework to be used in systemic interventions in management science/Operational Research (MS/OR) practice. The framework proposed incorporates key concepts from Maturana's Ontology of the Observer to complement Checkland's Soft Systems Methodology (SSM) application process. Checkland and Maturana are two systems thinkers whose work aim to understand and to improve problematic situations in organisations and in our everyday life; the proposed combined framework can have substantial implications to shed light into the SSM process. Checkland's ontological position (reality is problematic and unknowable) and interpretivist epistemology (multiple perceptions will enrich the ever-changing reality), resonates with Maturana's Ontology of the Observer (we are immersed in the praxis of living in an ontological multi-universe). There is common ground underpinning both approaches to make it feasible to combine and graft some of Maturana's key ideas (structural determinism/structural coupling and organisational closure) into some of the phases of the Checkland's well-known SSM seven-step process. An enriched and improved SSM process could have significant consequences in the OR/MS and Systems community practice. The framework proposed can have social repercussions since it will incorporate the well-known influential Maturana's Ontology of the Observer ideas into MS/OR practice.

■ WC-51

Wednesday, 12:30-14:00 - William Fry

Spatial Optimal Control in Resource and Environmental Economics

Stream: Optimal Control Theory and Applications
Invited session
Chair: Thorsten Upmann

1 - Growth abd agglomeration in a spatially heterogeneous environment
Fausto Gozzi

Abstract We introduce a general set-up for the study of a generic economy whose development process is entirely driven by the spatio-temporal dynamics of capital accumulation. To take into account spatial heterogeneity in technological level and population distribution the time-space capital accumulation which is formulated as a controlled second order deterministic PDE.

We briefly present some results obtained in the cases when an explicit (or semi-explicit) solution of the associated HJB equation can be found, in terms of eigenfunctions of an appropriate Sturm-Liouville problem. This allows to simulate the behavior of the variables and, in particular, their optimal discounted long-run spatial distribution. We briefly discuss the economic implications of such results.

Then we discuss the work in progress on more general cases, more precisely: - the case binding state constraints; - the case of nonlinear production function; - the stochastic case. - the multi-agent case

2 - Analytical characterization of optimal emission location strategies in a multiregional transboundary pollution differential game with spatially distributed controls
Javier de Frutos, Paula M. López Pérez, Guiomar Martin-Herran

We analyze a differential game modelling the strategic interactions among agents in a multiregional transboundary pollution control problem. The dynamics of the state variable (pollution stock) is defined by a parabolic partial differential equation. Pollution control is spatially distributed among a number, possibly large, of agents with predetermined spatial relationships. For a particular specification, we analytically characterize the feedback Nash equilibrium. We show that at the equilibrium both the level and the location of emissions of each region depend on the particular geographical relationship among agents.

3 - A two–player fish war with boundary fishing
Silvia Faggian, Thorsten Upmann, Hannes Uecker

In many spatial resource models it is assumed that agents are able to harvest the resource over the complete spatial domain. However, agents frequently only have access to a resource at particular locations at which a moving biomass, such as fish or game, may be caught or hunted. Here we analyze two-player infinite time horizon differential game, where space is one dimensional - a segment - with players fishing on different endpoints, and the dynamics is a semilinear parabolic PDE. We derive necessary conditions for Nash equilibria, consisting of a forward-backward semilinear diffusion system with boundary controls, and numerically compute the canonical Nash equilibria.

Wednesday, 14:30-16:00

■ WD-01

Wednesday, 14:30-16:00 - O'Reilly Hall

Piotr Faliszewski

Stream: Tutorials
Tutorial session
Chair: *Marta Szachniuk*

1 - Committee Elections: Applications, Axioms, and Algorithms
Piotr Faliszewski

In this talk I will give a short introduction to multiwinner elections. The idea of a multiwinner election is that a group of agents form opinions on a group of available candidates and based on these opinions—referred to as preferences—their goal is to select a committee of a given size. While multiwinner elections are often considered in the context of political elections (e.g., in terms of choosing parliaments or university senates), they form a very convenient formalims for modelling a number of other activities, such as selecting finalists of competitions, selecting products to offer on an Internet store's website, or selecting movies to offer on transatlantic flights. In this talk we will present the formalism of multiwinner elections, several voting rules, their axiomatic properties, connections between these properties and particular applications, and algorithms for computing election winners. This last issue is particularly important as computing results of multiwinner elections is often NP-hard, but there are very efficient workarounds, that drastically lower the complexity.

■ WD-03

Wednesday, 14:30-16:00 - Q106

Workshop: how hands on helps OR with benchmarks and challenges

Stream: Practice of OR (Making an Impact)
Tutorial session
Chair: *Alex Fleischer*
Chair: *Joaquim Gromicho*

1 - how hands on helps OR with benchmarks and challenges
Alex Fleischer, Joaquim Gromicho

We love a good puzzle, what about you? And are you in for a challenge? We believe that puzzles and challenges are great instruments to develop your OR skills. We will share our experiences and convince you that having fun makes you a better OR professional! We report on great puzzles, benchmarks and challenges and on our experience on using challenges as an instrument to teach OR. Kaggle is famous among the data scientists and prediction analytics professionals and has no comparable optimization counterpart, but there are many options to challenge and improve your optimization skills.

■ WD-06

Wednesday, 14:30-16:00 - A004

Decentralised Energy Systems and Demand Side Integration

Stream: Modelling & Analytics for Energy Economics I
Invited session
Chair: Lucas Condeixa
Chair: *Valentin Bertsch*

1 - Decentralized energy management: Optimizing virtual economic units
Benjamin Hildebrandt, Johann Hurink, Michael Manitz

As non-renewable resources are limited and the overall CO2 emissions need to be reduced drastically, there is an increasing interest in making the energy supply more sustainable. This leads to increasing research in the field of decentralized generation, storage and demand side management. In order to face the challenges for such a future energy management the consideration of the domestic level is gaining more attention In this talk we focus on economic issues as to whether and how the domestic level can participate in upcoming solutions. We introduce a virtual economic unit (VEU) consisting of a cooperation of domestic energy participants. We propose a deterministic linear optimization model for determining the energy load profiles of the participants of this basic VEU. Hereby the objective is profit-maximizing with individual tariff configuration. Additionally, we present a heuristic approach taking into account the bipartite structure of this problem. Numerical results for a basic set-up demonstrate the impact of peak-smoothing on the grid and the economic potential of combining decentralized generation.

2 - A customer oriented web tool for optimal sizing towards self-consumption building integration systems: A Spanish approach.
Marta Rodríguez Barreiro, Lucia Igualada, Josep Homs, Cristina Corchero

Nowadays, climate change is one of the most important challenges facing worldwide. As other European countries, Spain has been adopted measures in order to reduce the greenhouse gases emission. Among other efforts, public grants have been facilitating photovoltaic systems installation promoting a low-carbon economy and trusting on public and private buildings energetic self-generation and consumption when possible. In order to facilitate the user's decision making, in this work we present a web tool for sizing a self-consumption installation system. This tool is fully based on an OR optimization problem and it is totally directed toward Spanish consumers, which can introduce their own data and obtain the most suitable characteristics for their desired installation: BESS and/or PV. The model formulation in the background consists in minimizing not only installation but also operation costs over a one year time horizon. For BESS, a catalogue list of the market available BESS configurations are included. The PV energy production is estimated taking into account regional weather conditions as a temperature and radiation indicators. Regarding energy consumption, the web tool considers two different options: end users can provide their own annual consumption curve or, they can choose one from the different simulated curve types available at the tool database. These curves cover different building characterization such as location, number of inhabitants, contracted power.

3 - Developing a combinatorial optimisation approach to design geothermal-based district heating systems
Jann Weinand

Geothermal plants increasingly exploit the geothermal energy potential in Germany in district heating (DH) networks. In order to use this potential economically, municipal planners need transferable instruments for designing the DH network to supply households with the geothermal heat. This paper presents a combinatorial mixed-integer linear optimisation model and a three-stage heuristic to determine the minimum-cost geothermal DH systems in municipalities. The central innovations are the ability to optimise both the structure of the DH network and the location of the DH plant, the consideration of partial heat supply from DH and the scalability to many larger municipalities. A comparison of optimisation and heuristic for three exemplary municipalities demonstrates that the heuristic is between 500% and 1x107% faster than the optimisation. The resulting deviations in the calculated total investment for the DH system from the results of the optimisation are in all cases below 5%, and in 80% of cases below 0.3%. The efficiency of the heuristic is further demonstrated by the comparison with the Nearest-Neighbour-Heuristic. The latter is not only less efficient, it substantially overestimates the total costs by up to 80% in all cases with less than 100% DH heat coverage. Future work should focus on a more precise consideration of heat losses in the DH network, as well as taking additional geological conditions in the municipalities into account.

4 - Optimal sizing and location BESS in Distribution Systems: A linear approximation
Cristina Corchero, Cristina Núñez-del-Toro, Marcel Bernet

Energy transition oriented, this work deals with the optimal sizing and location of Battery Energy Storage Systems (BESS) for MV distribution networks. In this problem, bus location and sizing of BESS must be decided in order to minimize installation and operation costs given distribution network operational technical requirements. Typically, technical issues in distribution networks are considered through Optimal Power Flow (OPF) problems. In this manner, the problem in this work can be modelled as a Multi-period OPF problem. This formulation mainly arises two inconveniences. On one hand, solving an OPF for distribution networks is already difficult to solve, especially for larger networks. Additionally, multi-period problems makes larger and complex problems because of the number of variables and constraints are included. In this manner, a multi-period OPF can enormously grow even considering short time horizons. On the other hand, the addition of BESS installation and sizing variables to the model makes the problem to be MINLP. Solving the MINLP significantly increases the computational complexity of the problem making it unsolvable for small distribution networks and time horizons larger than two days. In order to reduce the computational time, in this work we propose a linear approximation for solving the BESS sizing and location problem for distribution networks. With the proposed formulation, solutions are found for test cases with time horizons of up to 3 months.

■ WD-07

Wednesday, 14:30-16:00 - A007

Group Decision Support Systems

Stream: Decision Support Systems
Invited session
Chair: Pascale Zaraté
Chair: *Francisco Ruiz*

1 - Crowdsourcing as Decision Support for Cities
Daniel OLeary

Crowdsourcing has been used in a number of settings in both industry and for public service. Crowdsourcing provides the ability to gather the wisdom of the crowd and to mitigate information asymmetries through information donations and evaluations. In so doing organizations, such as intelligent cities, can generate support from their members (citizens) to support decisions. For example, crowdsourcing can be used to gather information from the crowd about issues, such as, potholes, graffiti and traffic, and that information can be used to help guide resource allocations.

This paper develops three different analytic models to investigate why people participate as crowd sourcers in such settings. Those models focus generally on information asymmetries and gathering information about the crowdsourcing settings. The first model examines a network game based on the best shot payoff. Two cases, one with complete information and one with no information are analyzed and compared. The second model analyzes a game between two players for points in an app based on crowdsourcing behavior of being a first mover. The third model is a probabilistic cost-benefit model that examines potential information search behavior into being a crowd sourcer.

2 - Some notes on Consistency and Compatibility in AHP-Group Decision Making
Alberto Turón, José María Moreno-jimenez, Juan Aguarón, María Teresa Escobar

This paper analyses two of the most outstanding topics in AHP-Group Decision Making: the consistency, understood as the individual coherence when eliciting the judgments, and the compatibility, understood as the discrepancy between the individual positions and the collective position that synthesises them. For each of them, some of the indicators most used in the scientific literature for their evaluation are presented. Using the Geometric Consistency Index (GCI) and the Geometric Compatibility Index (GCOMPI), respectively for the evaluation of inconsistency and the incompatibility, an iterative procedure for the joint improvement of these two aspects is proposed. The procedure is illustrated by means of its application to a real-life situation (a local context) with three decision makers and four alternatives, in which three of the methods most used to obtain the group consensus matrix have been implemented: the Aggregation of Individual Judgments (AIJ), the precise consistency consensus matrix (PCCM) and the Dong method.

3 - A Visual Group-Based Screening Approach based on the Case-Based Distance Method
Li-Ching Ma, Pei-Pei Hsu

Screening is a process to filter out items which are improbable to be selected, and can condense a bigger set of items to a smaller set which decision makers are easier to focus on. The case-based distance method can find decision maker's preferences by selecting acceptable and unacceptable cases where distance between an alternative and a target point is deemed as an index to screen out less preferred items. The case-based distance method is easy to understand and implement; however, most of the cased-based distance methods screen alternatives individually, thus the efficiencies of screening may be insufficient when the number of alternatives considered is large. This study aims to propose a visual group-based distance approach to improve these limitations. This study proposes revised models to improve previous screening and displaying models. The idea of the similarity upper approximation is employed to provide group-based screening solutions. Compared to the previous methods, the major advantages of the proposed approach include (1) Group-based screening method rather than individual-based screening method can increase screening efficiencies. (2) The group of alternatives, relationships among alternatives and cases, and the acceptable ring can be visualized directly.

4 - A topic coverage based approach to conference-paper assignment
Francisco Ruiz, Jennifer Nguyen, Nuria Agell, Cecilio Angulo, German Sanchez

Assigning papers to reviewers is one of the most difficult and time-consuming tasks when a conference is organized. In the literature on "automatic paper-to-reviewer assignment" methods, assignments are normally based on reviewers' areas of expertise and preferences, and papers' topics. In these methods, this information is encoded into a global adequacy matrix whose elements represent the adequacy of reviewers to papers.

A standard assignment problem, such as a linear assignment, is typically solved by the Hungarian algorithm. However, this algorithm cannot be fully adapted to the constraints of the conference reviewer's assignment problem which imply that the number of reviewers and papers are not necessarily equal, each paper is reviewed by more than one reviewer, and each reviewer reviews more than one paper.

Formulation using an adequacy matrix does not ensure topic coverage, that is, reviewers assigned to a paper should ideally cover all topics and not just some of them. In this work we propose a formalization for the conference-paper assignment problem by maximizing the number of covered topics in papers using both Maximum satisfiability (Max-SAT) and Integer linear programming (ILP). The method proposed ensures that all topics in a paper are covered by the assigned reviewers. If complete coverage does not exist, the method maximizes the number of paper topics which can be covered.

■ WD-08

Wednesday, 14:30-16:00 - A008

Stochastic Orders in Financial Applications

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Francesca Maggioni*
Chair: *Milos Kopa*

1 - Performance of an enhanced index tracking model
Rosella Giacometti, Marco Bonomelli

One of the central topics in portfolio analysis is the stochastic ordering of financial portfolios. Such comparison is made with respect to assumptions on the investors' preferences and it is further developed with the concept of efficient dominance. In our study we apply this theory to the construction of an enhanced index tracking portfolio with the aim to replicate and outperform a benchmark. If there exist a solution, the optimal portfolio is dominant efficient on in-sample data. In our analysis we test whether it maintains its properties also ex post. To account for the data serial correlation, we adopt statistical tests constructed on parametric block-bootstrapped data generated under different distributional hypothesis and on non-parametric ones. Finally, we compare our replicating portfolio with other strategies, for example the equally weighted, the market portfolio and a riskless asset.

2 - Testing for parametric orderings efficiency
Sergio Ortobelli

In this paper, we develop and empirically compare semi-parametric tests to evaluate the efficiency of a benchmark portfolio with respect to different stochastic orderings. Firstly, we classify investors' choices when returns depend on a finite number of parameters: a reward measure, a risk measure and other parameters. Secondly, we propose a methodology to semi-parametric tests for the efficiency of a portfolio, when the return distribution is uniquely identified by four parameters, using estimation function theory. Finally, we empirically test whether the Fama and French market portfolio, as well as the NYSE and the Nasdaq indexes are efficients with respect to alternative stochastic orderings.

3 - Optimal portfolios with respect to Decreasing Absolute Risk Aversion Stochastic Dominance
Milos Kopa, Thierry Post

Portfolio optimization based on Stochastic Dominance (SD) is theoretically appealing, for investment strategies with asymmetric risk profiles such as equity price reversal and momentum plays. Most studies in this area are based on the second-order stochastic dominance (SSD) criterion. Unfortunately, SSD has limited discriminatory power, because it requires unanimity among all global risk averters, including those with implausible attitudes towards higher-order risk. SSD optimization therefore often produces solutions which are suboptimal for all standard utility functions. To improve the power of the analysis, the paper develops a portfolio optimization method based on Decreasing Absolute Risk Aversion Stochastic Dominance (DSD). DSD is known to be more powerful than alternative dominance criteria in several related financial applications and it is generated by the most restrictive class of utility functions acceptable to most economists. The proposed optimization method improves upon the performance of Mean-Variance optimization by tens to hundreds of basis points per annum, for low to medium risk levels. The improvements critically depend on imposing Decreasing Absolute Risk Aversion instead of Global Risk Aversion or Decreasing Risk Aversion.

■ WD-10

Wednesday, 14:30-16:00 - H0.12

Global Derivative-free Optimization and Applications in Multi-fidelity Problems

Stream: Derivative-free Optimization
Invited session
Chair: *Christine Shoemaker*

1 - Continuous Bionic Optimization in Engineering Applications
Rolf Steinbuch

The studies of the potential system responses in mechanical engineering often suffer from the large amount of computing time and computing power resources, which are necessary to analyze a single variant of the prospective design. Nonlinear numerical studies like the ones done by the use of large Finite Element models and complex loading histories require many hours of computing time on well-equipped computers even when we include essential parallelization. If we do optimization, we have to analyze many variants, which differ in many parameters from the initial idea. Therefore, the need of time and computing power is even larger. In addition, such nonlinear studies with many parameters tend to evolve many local maxima. In mechanical engineering, Evolutionary Optimization and Particle Swarm Optimization are among the most popular Bionic Optimization strategies, even if there exist many others. Bionic Optimization proves to be able to find good, if not even best results in many cases, as it does not depend on local responses of the design. Therefore, it reduces the danger to stick to local limits. But Bionic Optimization is always a time consuming process. We like to present some of the basics to enter the field of Bionic Optimization and explain some of the strong and weak points of its application. We focus here on nonlinear applications, but mention the problem of large linear problems with many parameters as well.

2 - Mesh Adaptive Direct Search Algorithms for Multifidelity Constrained Optimization
Mark Abramson

Multifidelity optimization occurs primarily in engineering design when multiple engineering simulation codes are available at different levels of fidelity. For example, optimizing the shape of an aircraft wing would typically require the computation of lift and drag, which can be computed using a full Navier-Stokes solver, an Euler solver, or a linearized potential code. High fidelity simulations are more accurate, but also more computationally expensive. The goal of this work is the design of algorithms that optimize with respect to the high-fidelity simulation, but exploit the use of lower fidelity codes as much as possible. Two new surrogate-based mesh adaptive direct search (MADS) algorithms are presented, in which interpolating surrogates are constructed and updated from previously evaluated iterates of the algorithm to speed convergence. The first algorithm employs a recursive Search step that optimizes a surrogate function constructed from the next lower fidelity level simulation augmented with an interpolating surrogate that accounts for the difference between adjacent levels of fidelity. The second approach is an augmentation of the optimization problem, in which the fidelity level is incorporated as a variable in the problem, but is constrained to be at the highest level of fidelity at the solution. Some numerical results are presented.

3 - DYCORS RBF Global Optimization Surrogate Much More Efficient than Gaussian Process-EI
Christine Shoemaker, Jin Yi

GP-EI (Gaussian Process Surrogate with an Expected Improvement acquisition function) was introduced in 1998 for surrogate global optimization of black box functions. It has been highly popular and has thousands of citations. However GP-EI is generally much less efficient for optimizing global optimization problems with dimensions of 10 or higher than are Radial Basis Function (RBF) surrogate methods like DYCORS introduced later. Both the GP-EI method and the DYCORS method are designed for objective functions that have multiple minima and that are expensive to compute, which implies the solution must be obtained with a relatively small number of objective function evaluations. In this talk we will provide extensive numerical results of comparisons on a number of global optimization problems and several widely used versions of GP-EI algorithm. We will discuss the differences between the two methods algorithmically and computationally over a range of kernel options. A major difference is that computing the RBF surrogate simply involves solving a linear system; the GP model however also has hyperparameters that must be estimated. For dimensions below 10, the RBF DYCORS method outperforms GP-EI methods somewhat. The RBF based DYCORS method is significantly better than GP-EI and more accurate at 10 and more dimensions over a wide range of problems.

4 - A Two-layer Radial Basis Function Surrogate and Dynamic Coordinate Search Algorithm for Computationally-expensive Global Optimization Problems with Multi-fidelity Models
Jin Yi, Christine Shoemaker

Engineering design optimization often involves computationally expensive simulation and analysis. How to find the optimal solution with low computation cost is a challenging task. This paper presents a two-layer radial basis function surrogate and dynamic coordinate search algorithm (MF-RBF-DYCORS) for computationally-expensive optimization problems when multi-fidelity models are available. MF-RBF-DYCORS has three main steps. In the first step, the RBF-DYCORS algorithm is used to search on the low-fidelity (LF) model. In the second step, a cluster algorithm is adopted to screen out potential points for the search on high fidelity (HF) model, and in the third step, the RBF-DYCORS algorithm is used again to search on the HF model. The performance of MF-RBF-DYCORS is validated through comparison with using only the high fidelity model with the following algorithms: the surrogate-assisted hierarchical particle swarm optimization (SHPSO), the hybrid surrogate-based optimization using space reduction (HSOSR), and the RBF-DYCORS algorithm. In addition, MF-RBF-DYCORS is compared to a multi-fidelity surrogate-assisted optimization method, the multi-fidelity Gaussian process and radial basis function-model-assisted memetic differential evolution (MGPMDE). These comparisons are done on 13 problems from a multi-fidelity optimization test suite and a real-world application of aero-dynamic shape optimization. The results show that MF-RBF-DYCORS outperforms all the compared methods.

■ WD-11

Wednesday, 14:30-16:00 - H1.12

Algorithms for Mixed-Integer Nonlinear Programming

Stream: Mixed-Integer Nonlinear Programming
Invited session
Chair: *Oliver Stein*
Chair: *Ivo Nowak*

1 - Granularity in Nonlinear Mixed-integer Optimization
Oliver Stein, Christoph Neumann, Nathan Sudermann-Merx

We study a deterministic technique to compute good feasible points for mixed-integer nonlinear optimization problems which satisfy a structural requirement that we call granularity. We show that solving certain purely continuous optimization problems and rounding their optimal points leads to feasible points of the original MINLP, as long as the latter is granular.

To this end we generalize results for the mixed-integer linear case from C. Neumann, O. Stein, N. Sudermann-Merx: A feasible rounding approach for mixed-integer optimization problems, Computational Optimization and Applications, 2018, DOI 10.1007/s10589-018-0042-y. We study additional issues caused by nonlinearity and show how they can be treated.

Numerical tests on the MINLPLib illustrate the potential of our approach.

2 - A Multi-Tree OA-Method for solving nonconvex MINLPs
Pavlo Muts, Ivo Nowak

We present a new multi-tree approach for solving nonconvex MINLP problems, called DECOA (Decomposition-based Outer Approximation). It solves block-separable mixed-integer nonlinear programming (MINLP) problems, defined by linking small sub-problems by linear (coupling) constraints. The solution is computed by alternately solving small sub-problems in parallel and a global mixed-integer (MIP) master problem. DECOA is called multi-tree since at each iteration it generates a new branch-and-bound (BB) tree for solving the MIP master problem. The master problem is defined by piecewise linear Outer Approximation (OA) of the nonlinear constraints, which are computed by reformulating the nonconvex functions as a Difference of Convex functions (DC). We present preliminary results using the MINLP-solver Decogo.

3 - Column Generation and CP Relaxation for Binary QCQPs
Enrico Bettiol, Immanuel Bomze, Lucas Létocart, Francesco Rinaldi, Emiliano Traversi

We consider the problem of minimizing a quadratic objective function with quadratic constraints and binary variables. We consider the extended formulation where the problem is linear on the matrix X, which represents the products of variables. In this framework, we relax the constraint linking X to the original variables and propose a column generation method based on Dantzig-Wolfe Reformulation that leads to a linear master and a pricing of max-cut type. We show that the domain of this relaxation is contained in the cone of Completely Positive matrices, hence it provides us with a tighter lower bound than the SDP one. With this strategy we can also easily add the quadratization of linear equality constraints: so, for linearly constrained problems, our formulation allows us to obtain an exact reformulation, due to an important result of Burer. This algorithm can thus solve the original binary problem without branching. The drawback is that the number of extreme points is exponential. We tackle the specific case of block-separable problems; in this case we show an adaptation of our algorithm which requires one pricing problem for each block. It allows us to obtain the same relaxation much more efficiently. Moreover, we extend this result to problems that are decomposable in partially overlapping blocks and show the conditions under which we can achieve an equivalent formulation. We provide computational results in support to our algorithm, for all settings considered.

4 - Combining Column Generation and Outer-Approximation for Solving Nonconvex MINLPs
Ivo Nowak, Pavlo Muts

We present a new algorithm for solving block-separable nonconvex MINLPs, called Decomposition Based Inner- and Outer-Refinement (DIOR). The approach is based on a (compact) resource-constrained reformulation of the MINLP, which is iteratively approximated by a MIP master problem. The algorithm starts by performing Column Generation (Inner Approximation) for initializing the master problem, where the sub-problems are solved using Outer-Aproximation (OA). In order to refine the master problem, new columns are generated by solving projection sub-problems for each block (using OA). Solution candidates of the MIP master problem are computed using Dynamic Programming. For each solution candidate more columns are generated by solving projection sub-problems, and the process is repeated until convergence. DIOR is implemented as part of the MINLP-solver Decogo. Preliminary numerical results will be presented.

■ WD-12

Wednesday, 14:30-16:00 - H1.51

Topics in Combinatorial Optimization III

Stream: Combinatorial Optimization I
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Silvano Martello*
Chair: *Paolo Toth*

1 - Combining Alternating Lagrangian Decomposition, Column Generation, and Dynamic Constraint Aggregation for a Personalized Airline Crew Scheduling Problem for Pilot/Copilot
Mohammed Saddoune, Vahid Zeighami, Francois Soumis

The airline crew scheduling problem involves determining schedules for airline crew members such that all the scheduled flights over a planning horizon (usually a month) are covered and the constraints are satised. Because of its complexity, this problem is usually solved sequentially in two main steps: the crew pairing followed by the crew assignment. However, nding a globally optimal solution via the sequential approach may be impossible because the decision domain of the crew assignment problem is reduced by decisions made in the pairing problem. This study considers the crew scheduling problem in a personalized context where each pilot and copilot requests a set of preferred flights and vacations each month. We propose a model that completely integrates the crew pairing and personalized assignment problems to generate personalized monthly schedules for a given set of pilots and copilots simultaneously in a single optimization step. The model keeps the pairings in the two problems as similar as possible so that the propagation of perturbations arising during the operation is reduced. We develop an integrated algorithm that combines alternating Lagrangian decomposition, column generation, and dynamic constraint aggregation. We conduct computational experiments on a set of real instances from a major US carrier. Our integrated approach produces signicant cost savings and better satisfaction of crew preferences compared with the traditional sequential approach.

2 - Bins and lateness minimization in one-dimensional packing problems with pattern-dependent processing times
Andrea Pizzuti, Fabrizio Marinelli, Wei Wu

The performances of a manufacturing process comprising a packing (or cutting) stage are often measured by evaluating both the space (or material) consumption and a function of the required processing time. In this work we address a one-dimensional packing problem enriched with scheduling features where a solution minimizing a convex combination of the number of bins and the maximum lateness is sought. In particular, we assume that items are provided by given due date, bins are processed sequentially and the processing time of each bin depends by the utilized pattern. We present a pattern-based integer linear program and solve its continuous relaxation by applying a column generation procedure. The resulting pricing is a quadratic integer problem that we solve by dynamic programming. Preliminary experiments compare the above procedure to a polynomial-size integer formulation in terms of quality of the dual bounds obtained and CPU time required.

3 - Dynamic Correlated Storage Assignment in Semi-automated Warehouses
Masoud Mirzaei, René de Koster

Order picking, the most critical operation in the warehouses, requires a lot of inbound and outbound activities. Companies like Amazon have improved picking productivity by actively scattering the units of a product over the warehouse shelves or reallocating part of the assortment. We propose a dynamic correlated storage assignment policy, using the data available on the customer demand, to reduce the total inbound and outbound effort in a semi-automated warehouse by simultaneously clustering the products on storage locations (pods) and dispersing inventory over the storage system. We define clusters of correlated products that are more likely to be requested together. Products can be assigned to multiple clusters to increase the correlation across clusters. We formulate the problem as a mixed integer program, and solve it over a rolling horizon. Since the problem is NP-hard, a heuristic is proposed to solve large instances of the problem. Preliminary results indicate improvement in the storage and retrieval time compared to random and turnover-based storage policies.

4 - Greedy algorithm based on the genetic optimization to construct a schedule for flight service staff
Andrius Kriščiūnas, Dalia Calneryte, Rimantas Barauskas

Rostering is a complex problem which is widely analyzed in the optimization area in order to create proper solutions in the acceptable time. After examination of the existing solutions, the algorithm which combines greedy solution and genetic optimization was proposed for the real-life airport ground staff timetable-scheduling problem. This algorithm is constructed of two steps. In the first step, the initial schedule is created based on the greedy solution approach in polynomial time depending on the number of workers and tasks. In the second step, the genetic optimization is performed with respect to the schedules created initially in the reconstruction. Using the proposed approach, it is possible to consider the requirements and different properties i.e. staff overtime, soft-constrained tasks, free-time periods etc., or weighted combination of them by defining weights in the evaluation function next to the proper parameter. The cascaded task assignments enable to take into account hard constraints such as worker holidays, working or non-working periods, which appear in real life. Testing has been performed using datasets of airport with more than 1000 flights per month and more than 50 ground staff persons. The analysis shows that the algorithm can be easily parallelized and adopted to big datasets.

■ WD-16

Wednesday, 14:30-16:00 - Theatre A

Matheuristics for Combinatorial Optimization Problems II

Stream: Combinatorial Optimization II
Invited session
Chair: Claudia Archetti

1 - A heuristic for the Air Traffic Flow Management Problem based on Data Analytics and Integer programming
Luigi De Giovanni, Carlo Lancia, Guglielmo Lulli, Davide Meneghetti

The scope of Air Traffic Flow Management (ATFM) problem is to guarantee a safe and efficient air traffic flow by computing 4D trajectories, one for each flight, that satisfy all the airports and en-route sectors capacity constraints. One of the current research efforts in the ATFM domain is to investigate formulations that consider Airspace Users' preferences, as recommended by the SESAR (Single European Sky ATM Research) programme. This is a quite challenging task because Airspace Users' preferences, which depend on many factors, e.g., costs, duration, geometry etc., are not always fully known. We consider a path-based integer programming formulation that assigns 4D trajectories to flights, and we develop a data-driven heuristic that i) learns Airspace Users' preferences and reduces the set of variables accordingly, and ii) solves the mathematical model. Using flight trajectories queried from Eurocontrol DDR2 data repositories, the learning phase determines relevant trajectories via clustering, and applies data analytics tools, mainly tree classifiers, support vector machines and multiple regression, to explore the relation between trajectories and potential preference determinants. As a result, a set of trajectories and information on related Airspace Users' preferences is computed for each flight. These sets feed the optimization model for the assignment phase.

2 - Air intermodal freight transportation: the Freight Forwarder Service Problem and Model Formulations
Lorenzo Peirano, Claudia Archetti

Despite being one of the most relevant figures in international multimodal transportation, freight forwarding companies optimization problems did not receive much attention from the research community. In this work we try to fill this gap by presenting the general features of air transportation from the freight forwarder's perspective and we introduce the air transportation freight forwarders service problem (ATFFSP). A MILP formulation of the problem is proposed and tested on real-life data coming from an Italian freight forwarding company. We study the performance of the model in terms of optimality gap and time needed to reach the optimal solution. Furthermore we compare the solutions found with the ones provided by the company in order to evaluate the effectiveness of the model and its ability to find good and practical solutions. We also propose a setpartitioning formulation for the problem and an exact solution approach based on complete enumeration of feasible routes. Further, we present heuristic algorithms exploiting the same formulation. Computational tests are made on instances proposed in the literature which are based on real data. The results show that complete enumeration is not a practical method to find a solution, while the proposed heuristics and acceleration methods are capable of offering good solutions for large size instances.

3 - An MIP-based Variable Neighborhood Search for the Blocking Job Shop Scheduling Problem
Julia Lange, Reinhard Bürgy

The blocking job shop scheduling problem (BJSP) is a combinatorial optimization problem, in which a set of jobs has to be processed on a set of machines according to individual technological routes while facing a lack of intermediate buffers in the system. This problem appears, for example, when scheduling jobs in flexible production environments, trains in railway networks and robots in automated warehouses. To model customer satisfaction and reliability, the goal is to find a schedule with minimal total tardiness. Schedule feasibility issues make the BJSP particularly challenging. Typically, the problem is tackled by combinatorial heuristics, since there exists no method to solve BJSP instances of practically relevant size to proven optimality. Advanced mixed-integer programming (MIP) solvers do even struggle in constructing good feasible schedules. Motivated by these observations, an analysis of the performance of general MIP heuristics on BJSP instances is conducted and scheduling-tailored MIP methods are proposed. A matheuristic that integrates promising techniques into a variable neighborhood search (VNS) is developed. Computational experiments are performed on a diverse set of benchmark instances. It can be observed that the VNS substantially improves the solutions of the generic and scheduling-tailored MIP heuristics and outperforms general-purpose solvers. The results show that this is a promising research direction for solving complex job shop scheduling problems.

■ WD-17

Wednesday, 14:30-16:00 - A005

Generation and transmission expansion planning under uncertainty

Stream: Technical and Financial Aspects of Energy Problems
Invited session
Chair: Luis Baringo

1 - Addressing flexibility issues in clustered unit commitment formulations for generation expansion planning models
Diego Tejada, Germán Morales-Espana, Sonja Wogrin, Efraim Centeno Hernáez

This work proposes a Clustered Unit Commitment (CUC) formulation to accurately model flexibility requirements such as ramping, reserve, and startup/shutdown constraints. The classic CUC intrinsically and hiddenly overestimates the individual unit's flexibility, thus being unable to replicate the result of the individual UC. Different case studies show that the proposed CUC correctly represents the individual unit's flexibility within the cluster and how it is applied to long-term planning models without significantly increasing their computational burden.

2 - Generation Expansion Planning under uncertainty: Stochastic Dual Dynamic Integer Programming (SDDiP) and parallelization scheme
Cristiana Lara, Ignacio Grossmann

We address the long-term planning of electric power infrastructure under uncertainty. We propose a Multi-stage Stochastic Integer Programming formulation that optimizes the generation expansion to meet the projected electricity demand over few decades while considering detailed operational constraints [1], intermittency of renewable generation, power flow between regions, and uncertainty (e.g. peak load demand, fuel price, carbon tax uncertainties). To be able to solve this large-scale model, which grows exponentially with the number of stages in the scenario tree, we decompose the problem using Stochastic Dual Dynamic Integer Programming (SDDiP) [2]. The SDDiP algorithm is computationally expensive but we take advantage of parallel processing to solve it more efficiently [3]. We report results for a case study in the region managed by the Electric Reliability Council of Texas.

[1] Lara, C.L., Mallapragada, D.S., Papageorgiou, D.J., Venkatesh, A. & Grossmann, I.E. (2018) "Deterministic electric power infrastructure planning: Mixed-integer programming model and nested decomposition algorithm", European Journal of Operational Research. 3. 1037-1054. [2] Zou, J., Ahmed, S. & Sun, X.A., (2018). "Stochastic dual dynamic integer programming", Mathematical Programming. 1-42. [3] Helseth, Arild & Braaten, Hallvard. (2015). Efficient Parallelization of the Stochastic Dual Dynamic Programming Algorithm Applied to Hydropower Scheduling. Energies. 8. 14287-14297.

3 - Robust Transmission Expansion Planning with Uncertain Wind Generations and Loads using Level III Strutural-Reliability Methods
Cristina Roldán, Roberto Mínguez, Raquel García-Bertrand

Transmission network expansion planning (TNEP) analyzes the issue of how to expand or reinforce an existing power transmission network so that adequately serves system loads over a given time horizon. Recent advances on robust TNEP problems proved that Adaptative Robust Optimization constitutes an efficient solution method to make them tractable for real systems. However, the use of cardinality constrained uncertainty sets makes the interpretation of final results difficult from a probabilistic viewpoint, and the hypothesis that uncertain parameters follow a symmetric distribution within the selected intervals does not match reality, specially for power production associated with wind generation. The recent use of level II structural-reliability and decomposition techniques allows the efficient incorporation of ellipsoidal uncertainty sets, which allows to consider the correlation structure of uncertainty sources through the use of their expected values and the variance-covariance matrix (First-Order Second-Moment, FOSM). However, it also constitutes an approximation. This work presents an iterative method which, using FOSM and modifying appropriately the reliability index associated with the desired objective function quantile, transforms the model into a Level III structural-reliability method that allows the consideration of the complete probabilistic structure of the uncertain parameters involved and the calculation of the operating costs probability distribution.

4 - Nested Column-and-Constraint Generation Algorithm for the Robust Transmission Network Expansion Planning Problem Considering Storage Units
Luis Baringo, Álvaro García-Cerezo, Raquel García-Bertrand

We propose an adaptive robust optimization approach for the transmission expansion planning problem considering storage units. The problem is formulated as a three-level optimization problem. As a distinctive feature, we include binary variables to avoid the simultaneous charging and discharging of storage units. This prevents the use of a traditional column-and-constraint generation algorithm to solve the three-level problem. Therefore, we propose the use of a nested column-and-constraint generation algorithm that guarantees convergence to the global optimum in a finite number of iterations. The performance of the proposed model is illustrated using the Garver's 6-bus test system.

■ WD-18

Wednesday, 14:30-16:00 - C112

Statistical Disclosure Control II

Stream: Data Mining and Statistics
Invited session
Chair: *Goran Lesaja*
Chair: *Anna Oganian*

1 - Robust Statistics: Ideas for Differential Privacy and Utility
Roberto Molinari, Aleksandra Slavkovic

The potential advantages of using robust statistics for privacy have already been discussed in the existing literature. However there has been little investigation on how robustness can preserve differential privacy as well as deliver statistical accuracy from the private outputs. In this talk we provide an overview of some basic elements of robust statistics that can be of relevance to privacy. The idea we want to investigate is whether existing privacy mechanisms can be improved in terms of (statistical) utility by making use of these approaches. Preliminary results indicate that these approaches, in addition to recently proposed bias-correction methods, can be worth investigating further and employed more abundantly within privacy-preserving mechanisms.

2 - Synthetic data and differential privacy
Gillian Raab

Differential privacy (DP) (Dwork, 2006) is considered by theoretical computer scientists to be the most rigorous system of protecting the privacy of data released to the public. In its original form it focussed on privacy without reference to utility. In contrast, the generation of synthetic data, as implemented in our synthpop package for R has had utility as its main concern. The original conception of DP was that a DP mechanism would be designed to answer individual queries, or series of queries. Some recent developments allow synthetic data to be generated. This allows direct comparisons to be made between synthetic data and DP data with respect to utility and disclosure control. Results comparing the two approaches will be presented for categorical data.

3 - Synthetic Data Challenge
Jennifer Taub, Gillian Raab

Data synthesis is an alternative to controlling confidentiality risk through traditional statistical disclosure control (SDC) methods. There are several different techniques used to produce synthetic data; the goal of all of them is to produce useful data while maintaining very low disclosure risk. An important and live research goal is the development of credible measures of both the risk and utility of synthetic data. Without such credible measures, it is difficult for analysts and data owners alike to trust synthetic data or to know which data synthesis methods work best (for their data). As part of the Isaac Newton Institute programme on Data Linkage and Anonymisation in 2016, we ran a challenge to test various synthetic data generation methods against one another. Four different research teams produced a total of eight synthetic versions of the same dataset using different synthetic data production methods. The synthetic datasets were then put through a battery of tests for both data utility and disclosure risk. The challenge study has produced significant insights not only about the synthetic data generation techniques, but also about the effectiveness different measures capture utility/risk of synthetic data.

4 - On Clustering Using Privacy Preserving Data
Pauline O'Shaughnessy, Yan-Xia Lin

In this data age, Data Mining provides feasible tools to handle large dataset, in which Operational Research contributes significantly to the various aspects, from data collection, preparation and cleaning, to analysis and visualization. However little research has been done in Data Mining when data privacy is of concern. It is of urgent interest to develop feasible methods allowing application of data mining techniques to confidential data. In the paper, we propose a disclosure control method combining noise multiplication and synthetic data generation for data clustering, following a three-step process, i.e., (i) reconstruct the density function of the original data using noise-multiplied data; (ii) generate a set of synthetic data from the reconstructed density faction; then (iii) apply the data clustering technique to the synthetic dataset. The proposed method is evaluated through simulation study and we show the application of the method in real data.

■ WD-19

Wednesday, 14:30-16:00 - C115

Emerging Applications in Management Science: Business and Public Administration

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: Sheldon Jacobson

1 - The impact of knowledge managers' productivity on knowledge management processes and organizational innovation
Sebastian Ion Ceptureanu, Giulia Rotundo

The paper proposes an innovative research model to investigate the mediating role of knowledge managers' productivity on knowledge management processes and organizational innovation. The results indicate that K managers' productivity mediates between knowledge management processes and organizational innovation, providing new insights on K managers roles in knowledge-based innovation.

2 - An optimization model for the planning of surveillance operations in national parks
Alfredo Candia-Véjar, José Andrés Moreno-Pérez, Javier Gomez-Lagos

A new optimization model is proposed to model the problem of defining a surveillance system in national parks. The model basically considers two types of mechanisms to apply in vulnerable areas and risk situations in national parks. One mechanism relies on a group of park guards, while the other depends on a set of dedicated drones that must collaborate in the surveillance operations. The problem is modeled by a mixed linear integer programming formulation and it is illustrated with an application in a Chilean park.

3 - A Multi-criteria Approach to Political Redistricting
Sheldon Jacobson, Rahul Swamy, Douglas King

Political redistricting is a multi-objective problem with conflicting objectives such as compactness, population balance, among others. While the problem is well-studied, the use of political fairness metrics has been relatively under-explored. In addition, contiguity enforcement within an exact method has been a challenging task. This research presents a multi-objective approach explicitly considering political criteria such as efficiency gap and competitiveness within a branch and cut framework. The results demonstrate a number of issues, such as that compactness does not always ensure political fairness.

■ WD-20

Wednesday, 14:30-16:00 - C006

Applied Queueing Theory for automated warehouses

Stream: Automated Warehouse System
Invited session
Chair: Sonja Otten

1 - Determinating the optimal number of robots with queueing theory in robotic mobile fulfillment systems
Sonja Otten, Ruslan Krenzler, Lin Xie, Karsten Kruse, Hans Daduna

Robotic mobile fulfillment systems are a new type of warehousing system, which has received more attention recently, due to increasing growth in the e-commerce sector. Instead of sending pickers to the storage area to search for the ordered items and pick them, robots carry shelves including ordered items from the storage area to pick stations. At every pick station there is a person - the picker - who takes items from the shelves and packs them into boxes according to customers' orders. In these fulfillment systems there are many decision problems. We focus on decisions about the optimal number of robots. We construct a queueing network, model the robotic mobile fulfillment system as a Markov process and do stability analysis.

2 - A queueing approach for performance analysis of automated storage and retrieval systems under single-command cycles
Anja Heßler, Christoph Schwindt

Appropriately dimensioning a storage and retrieval (S/R) system requires a reliable performance prediction, which can be obtained by analyzing the system throughput under steady-state conditions. The expected maximum system throughput is largely influenced by the S/R strategy. Disregarding the time savings achieved by optimally operating the warehouse may heavily bias the performance analysis. We investigate the limiting performance of an S/R system executing single-command cycles to serve a random storage. We assume that S/R requests are released according to independent Poisson processes and are executed in the sequence of their arrivals. As a storage assignment strategy we consider the closest eligible location (CEL) rule, which for each request selects the storage location with minimum total cycle time. The CEL rule maximizes the expected throughput of an S/R system executing single-command cycles. For the performance analysis, we propose a mathematical model relying on Gordon-Newell networks. We show how to construct a collection of closed queueing networks whose steady-state behaviors describe the long-run performance of the S/R system. Based on a stationary analysis of these networks, we obtain closed-form expressions for relevant key performance indicators. Furthermore, we present an approximate generalized queueing approach for arrivals following independent renewal processes and validate the results against numerical simulation.

3 - Stochastic Models for Robotic Sorting Systems
Yeming Gong, René de Koster

Many distribution centers use expensive, conveyor-based sorting systems that require large buildings to house them. In areas where space is tight, robotic sorting (RS) systems offer a new type of solution to sort parcels by destination. Such systems are highly flexible in throughput capacity and are now gradually introduced. We focus on performance estimation and optimization of operating policies, while taking into account robot blocking and congestion. Robots travel via a shortest-path route along bidirectional aisles and detour robots travel via unidirectional aisles. Different rules for assigning robots to workstations are investigated, including shortest, closest and random queue assignments. Moreover, we design a travel-distance based heuristic to locate the distribution of drop-off points over the network to improve the throughput capacity of the system. We develop a closed queueing network for performance estimation capturing different scenarios. We validate analytical models through simulation and then optimize the operating policies in terms of system throughput capacity and operating cost.

■ WD-21

Wednesday, 14:30-16:00 - F101

Graph Partitioning and Connected Components

Stream: Algorithms on Graphs
Invited session
Chair: Diego Recalde

1 - Persistent Connected Components on Temporal Networks
Mathilde Vernet, Yoann Pigné, Eric Sanlaville

The problem of finding connected components in graphs is not as trivial as it seems when working on dynamic graphs. We propose an original bi-objective optimization algorithm on connectivity on temporal networks. We study undirected networks on a finite discrete time horizon during which edges can appear and disappear. Our objective, in such network, is to find the largest non-dominated persistent connected components according to two criteria: the size of the connected component in number of vertices and the length of the connected component in number of consecutive time steps it is present on. We propose a polynomial-time algorithm working on a temporal network able to compute the non-dominated persistent connected components. Those components form a Pareto front. Each one of them has at least as much vertices and is present on at least as much time steps as the other connected components of the network. The advantage of this algorithm is that it works online. Knowing the evolution of the temporal network is not necessary to execute this algorithm. A connected component at a given time step can be represented as a label on a vertex indicating the component it belongs to. Finding a persistent connected component is then equivalent to finding a common sequence of labels on vertices. Similar problems can be encountered in molecular biology where one wants to detect common nucleic acid sequences between DNA molecules.

2 - Top-k-Overlapping Densest Subgraphs for Network Mining
Mohammad Mehdi Hosseinzadeh, Riccardo Dondi

A fundamental problem in network mining is the identification of dense subgraphs, since they are considered to be related to relevant parts of networks, like communities. Most of the previous works focused mainly on computing a single dense subgraph, but in many applications, it is of interest finding more than one subgraph. Some combinatorial approaches have been recently proposed to compute a set of dense, possibly overlapping, subgraphs. In this paper we consider one of these approaches, called Top-k-Overlapping Densest Subgraphs, that aims at finding a set of k dense subgraphs, for some integer k >= 1, that maximize an objective function that considers both the density of the subgraphs and the distance between them. In this paper, we propose a new heuristic for Top-k-Overlapping Densest Subgraphs and we present an experimental analysis that compares our heuristic with an approximation algorithm, called DOS, previously introduced in literature to deal with this problem. We compare our heuristic with DOS on synthetic and real networks. The experimental results show that, in the majority of synthetic graphs our heuristic is better than DOS, and on ten real networks ranging from 962 to 30149 vertices, our heuristic always produces better solutions. Our heuristic provides solutions that are denser than those computed by DOS, while the solutions computed by DOS have a greater distance. On the other hand, the DOS algorithm is much faster than our method.

3 - A multilevel algorithm for rich hypergraph partitioning problems
Gabriel Gouvine

Partitioning an hypergraph with minimum cut under capacity constraints is a well-known NP-hard optimization problem. It has direct applications in distributed computing, electronic circuit design and social network analysis. In these domains, typical hypergraphs can contain millions of nodes.

State-of-the-art algorithms are based on a multilevel approach, where a local search algorithm is applied to coarsened versions of the hypergraph. However, major heuristics such as hMetis, KaHyPar and PaToH are tailored to a specific version of the problem. This enables very efficient algorithms, such as the Fiduccia-Mattheyse algorithm and the heavy-edge coarsening heuristic. On the other hand, they cannot handle many of the real-world constraints and cost functions that arise in practical problems.

We propose a partitioning algorithm that does not assume a particular objective function or constraint type. It considers the problem as a black box, and only needs to query the objective function value of a solution. To this effect, we design a new heuristic that makes use of the best solutions found so far to decide how to coarsen the problem's graph.

We test our algorithm on partitioning benchmarks and show that the solution quality is competitive with dedicated algorithms. We then present results on new classes of problems, with multidimensional packing constraints and nonlinear objective functions, as are typically found in electronic design.

4 - The multi-weight graph partitioning problem
Diego Recalde, Ramiro Torres, Polo Vaca Arellano

In this work a multi-weight graph partitioning problem is introduced. This problem consist in partitioning an undirected graph in a fixed number of subgraphs such that multiple node weight constraints over each partition are satisfied and the total distance between nodes in the same subgraph induced by the partition is minimized. This problem generalizes several graph partitioning problems like the k-way equipartition, balanced k-way partition with weight constraints, size constrained, general graph, equipartition and bisection problem. It arises in a real-world subproblem of an integrated vehicle and pollster problem as well as in a police personnel assignment. Two Integer Programming formulations are provided and several families of valid inequalities associated to the respective polyhedra are proved. An exact algorithm based on branch and bound and cutting planes is proposed and it is tested on simulated and real-wold instances.

■ WD-22

Wednesday, 14:30-16:00 - F102

Energy Management

Stream: Sustainable Supply Chains
Invited session
Chair: *Carolien Lavigne*

1 - Sustainability Evaluation of Brazilian Energy Companies using Data Envelopment Analysis
Lidia Angulo Meza, Mozart Heymann, Rodrigo Caiado, Celso Silveira, Oswaldo Quelhas

Given the increasing depletion of resources and the continued lack of worthy work opportunities, the pursuit of environmental and social issues aligned with economic growth becomes the major goal for many organizations. This paper aims to analyze sustainability performance of a group of Brazilian electrical energy companies, using radial and non-radial Data Envelopment Analysis (DEA) models. To do this we consider both the economic and social dimensions of sustainability. Therefore, we determine the eco-efficiency and socio-efficiency of 42 companies, this is done considering two social variables and two environmental variables as inputs with one economic output. We identify the most efficient companies considering one or both of the sustainability dimensions, we determine the best practices and improvement targets for the inefficient. Moreover, the efficiency indexes have managerial and political implications that we detect. This work emphasizes the importance and the use of DEA models in the sustainable development context.

2 - Environmental benefits of a second-generation bioethanol production network designed by integrating Life Cycle Assessment and supply chain network optimization
Lars Wietschel, Lukas Meßmann, Andrea Thorenz, Axel Tuma

Second-generation (2G) ethanol is a promising substitute for fossil resources in applications like solvents, intermediates in the chemical industry, or fuel. Agricultural residues, one of the most promising feedstocks, exceed a bioeconomic potential of 110 Mt (equal to 1.925 PJ). We investigate the optimal design of an upscaled European 2G bioethanol network that maximizes environmental benefits of 2G ethanol compared to 1G ethanol and fossil fuels under the requirement of competitive litre prices. We design a multi-criteria MIP model for optimal decisions on residues provision and collection, transportation modes, locations and capacities of bio refineries, and bioethanol distribution in 'cradle-to-tank' system boundaries. The model includes 21 environmental objectives with parameters based on LCA (18 midpoints and 3 endpoints, based on ReCiPe 2016). To assure the economic competitiveness of 2G bioethanol, specific network costs are implemented as satisficing goal. Results show that a maximum 2G ethanol production volume of 22 Mt could be realized today. This corresponds to about 650 PJ of energy that could be used from agricultural residues without compromising the regional straw demand. When directly substituting fossil-based fuels, over 40 Mt of CO2 can be saved, which corresponds to 1 per cent of today's European Union's annual carbon emissions. Sensitivity analyses shows that the results depend on the choice for allocation methods for environmental impacts.

3 - Vehicle-to-grid (V2G) implementation in Germany - a viable and sustainable business model for established companies in the automotive sector
Elisabeth Burkhart, Peter Letmathe

Governmental regulations on reducing greenhouse gas emissions are leading to an extensive electrification of the transportation sector. Now, car manufacturers are shifting their product portfolio towards electric vehicles (EVs) to be able to comply. It is estimated that every third car will be an EV by the year 2030. Studies also have shown that cars are in use only 4% of the time, so batteries of EVs could form, in aggregate, a very large source of energy storage and thus transmit power back to the grid when demand is high. Especially in the context of the German Energiewende, this technology concept, vehicle-to-grid (V2G), is a promising approach. Although proven to be technologically feasible, no viable business model for V2G has emerged so far, raising the question how it should be constituted. As we are stepping into the interface between the energy and mobility sector, this question is especially relevant with regards to economically feasible as well as sustainable business models for established companies in the automotive sector. Selling EVs while leasing batteries to their customers, an automotive company can act as an aggregator and sell large blocks of electricity into the regional power market, thereby offering ancillary services such as regulation and reserve power. First results from a simulation of a V2G implementation in Germany reveal reasonable revenue streams generated by offering secondary control reserves.

4 - A location-routing optimization and simulation model for biowaste collection in the Brussels Capital Region
Carolien Lavigne

The latest amendment to the EU waste directive in 2018 obligates all member states to collect and treat biowaste separately by December 2023. In light of these new requirements, the Brussels Capital Region is investigating alternative biowaste collection and treatment schemes. Currently, garden waste is only collected in specific neighborhoods while food waste is collected throughout the region but only on a voluntary basis. Of the estimated amount of biowaste generated, only 9% is collected separately (2014 data). The remainder is collected jointly with residual waste and is incinerated with energy recovery. We estimate the impact of scenarios such as more ambitious collection rates, joint versus separate collection of food and green waste and alternative processing locations on waste collection costs. A location-routing optimization and simulation model was developed which minimizes transportation costs for each scenario. Furthermore, for each scenario the associated externality costs such as emissions, noise and accidents are calculated assisting the BCR's environmental authorities in balancing conflicting policy objectives like cost efficiency and minimal environmental impact.

■ WD-23

Wednesday, 14:30-16:00 - F103

Graphs and Networks

Stream: Graphs and Networks (contributed)
Contributed session
Chair: *Mirko Vujosevic*
Chair: *Hayette Gatfaoui*
Chair: *Tugce Yucel*

1 - Change Point Detection in Partial Correlation Networks
Jessica Wai Yin Leung, Dmytro Matsypura

In this study, we are interested in the problem of change point detection in the structure of similarity network over time. Correlation matrix is commonly used in constructing similarity networks. Yet, it is well-known that it suffers from the illusion of spurious relationships within the system. Therefore, we adopt the partial correlation matrix as an alternative similarity measure and develop a statistical testing procedure that is tailored to such construct with minimal distributional assumptions. Preliminary simulation results show that our test has high statistical power across different sample sizes and dimensions.

2 - Computing skeletons for obstacles in network and motion planning problems in the plane
Marcus Volz, Marcus Brazil, Charl Ras, Doreen Thomas

We introduce the concept of an obstacle skeleton which is a set of line segments inside a polygonal obstacle that can be used in place of the obstacle when performing intersection tests for obstacle-avoiding network problems and motion planning problems in the plane. A skeleton can have significantly fewer line segments compared to the number of line segments in the boundary of the original obstacle, and therefore performing intersection tests on a skeleton (rather than the original obstacle) can potentially significantly reduce the CPU time required by algorithms for computing solutions to obstacle-avoidance problems. A minimum skeleton is a skeleton with the smallest possible number of line segments. We provide an exact algorithm for computing minimum skeletons for rectilinear obstacles in the rectilinear plane that are rectilinearly convex (obstacles whose edges are either horizontal or vertical and for which any two points in the obstacle have a shortest rectilinear path that is entirely inside the obstacle). We show that a minimum skeleton for any rectilinearly convex obstacle has at most half as many edges as those in the boundary of the original obstacle. We then discuss the extension of these ideas to convex and non-convex obstacles in other fixed orientation metrics as well as the Euclidean metric, and in the context of other obstacle-avoidance problems.

3 - Extended center description and neighbor-copy with improvement of wireless sensor networks
Tugce Yucel, Aysegul Altin-Kayhan

We aim to optimize the lifetime of wireless sensor networks, which consist of one data collector base station (BS) and numerous randomly scattered sensors with limited energy. Network lifetime is measured as the time until the first sensor exhausts its battery. Moreover, we incorporate network security via balanced utilization of sensors and multiple copying against possible external attacks or breakdowns. The amount of data each sensor can receive from others is limited from above by some constant. However, if it would improve network lifetime then only one sensor is allowed to exceed the limit and become a central node. Due to its critical role in data flow, the central node is more likely to be exposed to external attacks or possible breakdowns. To this end, we propose a partial multi-copy strategy where sensors transmitting data to the central node would copy that data and send it to the BS through node-disjoint paths. Consequently, we can avoid unnecessary data copying to some extend and use energy more efficiently. Transmitting extra data at the expense of extra energy would shorten the network lifetime. Hence there is a tradeoff between network lifetime and network security. We present the mixed-integer programming model of the problem and an optimization based heuristic algorithm developed especially for solving larger instances. We analyze the performance of these solution methods on a large tested.

■ WD-24

Wednesday, 14:30-16:00 - F103A

Perspectives on Supply Chain Management

Stream: Supply Chain Management
Invited session
Chair: *Magdalena Kalata*

1 - New fuzzy dispatching rules for integrated planning and scheduling across supply chain
Magdalena Kalata, Dobrila Petrovic, Sanja Petrovic

In this study, a complex, multi-echelon integrated planning and scheduling problem is considered. A Supply Chain (SC) consists of four echelons, including Suppliers, Manufacturer, Distribution Centres and Customers. All echelons have their own scheduling and inventory control policies. Also, the echelons have different Key Performance Indicators (KPIs); for example, for Suppliers they are machine utilisation, machine setup times and delays in delivery to the manufacturer, for Manufacturer they are delays in delivery to the distribution centres and holding cost for end products and raw materials and for Distribution Centres they are cost and utilisation of available trucks, while SC aims to deliver customer orders on time, as much as possible, with the smallest possible cost incurred. However, the impact of scheduling and inventory control decisions made at a single echelon propagate through entire SC, and affect overall SC performance. We developed new fuzzy dispatching rules for each echelon which aim at making a trade-off between considered KPIs at each echelon. They are specified in the form of fuzzy If-Then rules and operate by using an approximate reasoning method. Various experiments are carried out to analyse the performance achieved by applying the fuzzy dispatching rules. They are compared with standard dispatching rules such as First-in-First-Served, Earliest Due Date, Most Total Work Remaining and Least Total Work Remaining.

2 - Algebraic tools in supply chain management
Gerasimos Meletiou, Miguel Couceiro, Konstantina Skouri

Present trends in supply chain management, like supply chain differentiation, competitive positioning and performance management, require the synthesis of, usually contradictory, features of objects. The choice of the aggregation procedure to perform feature synthesis constitutes one of the major issues in efficient supply chain management due to its complexity and the number of problems at various management levels. In this presentation we shall explore algebraic tools for the construction of such aggregation procedures. Our approach is rooted in classical order theory, consensus/aggregation functions, and it borrows techniques from computational social choice.

3 - Supply Chain Value Analysis and Streamlining
Ali Ardalan

Significant progress has taken place since Skinner published his ground breaking idea about focused factory that was published in Harvard Business Review in May 1974. Innovative production techniques supported by flexibility in production resources and enormous power of information technology. Competition has continued to force organizations to become more responsive to customer taste and more agile with respect to production. The pressure exerted on organizations by competitive forces has forced organizations to consider external factors that include supply chains and their entities. Supply chain research is broad and extensive. The role of communication among entities for improving supply chain performance and risk management has been well established. Mathematical and simulation models have been developed and tested to understand their behavior and provide managers with information to manage them. This paper recommends a detailed analysis of supply chain entities and their contributions to the success of the supply chain. The detailed analysis reveals the production competencies of the individual entities relative to the supply chain. Through negotiations between supply chain managers and managers of individual entities, each entity is assigned certain production responsibilities. An entity may be required to focus its operation on a limited number of product types.

■ WD-25

Wednesday, 14:30-16:00 - F104

Quantitative Decision Support Methodologies for Supply Chain Planning and Control II

Stream: Production, Service and Supply Chain Management (contributed)
Contributed session
Chair: *Roberto Dominguez*
Chair: *Salvatore Cannella*
Chair: *Pablo A. Miranda*

1 - Modeling and Solving an Inventory Location Problem with Unfilled Demand Costs and Service-Level Optimization for Supply Chain Network Designing
Pablo A. Miranda, Francisco J. Tapia-Ubeda

In the last decades the Inventory Location literature has vastly growth and developed for addressing a variety of supply chain network design problems. These models usually integrates inventory control decisions and costs under stochastic demands into strategic facility location models for warehouse location purposes. Most of these models assume fixed and known desired stock-out probabilities. In contrast, considering the traditional (s, Q) Inventory Control Policy, this paper enhances the literature by proposing an Inventory Location model that integrates unfilled demand costs, where the stock out probability is jointly optimized. In addition, and optimization algorithm is developed based on the Generalized Benders Decomposition. Some preliminary results are shown manifesting the effectiveness of the proposed approaches to address Supply Chain Network Design problems.

2 - On the salmon production and transport planning in a freshwater stage with mobile cages allocation
Oscar Romero-Ayala, Pablo A. Miranda, Gabriel Gutiérrez-Jarpa, Francisco J. Tapia-Ubeda

Fish consumption faces a significant and persistent increment worldwide, where the salmon production is essential to cover the projected demands. The salmon production cycle mainly comprises three stages: freshwater (fish cultivation and handling), seawater (weight gain) and plant processing. Each stage has its own characteristics related to the geographical location, service and raw material providers, and regulations, among other issues. This research focuses on the freshwater stage, which is compounded by a number of serial productive substages. This work proposes new Mixed Integer Programming models for salmon production and transport planning between the freshwater sub-stages in a multi-period scenario. The main contribution relies on integrating cages mobility between the farming centers located at each fresh water sub-stage. The model allows to determine the required cages as well as their allocation to the farming centers for each period within the planning horizon. In addition, a Lagrangian Relaxation-based algorithm is proposed in order to efficiently solve the proposed model.

3 - Joint Inventory Planning and Pricing When Launching Innovations
Alejandro Lamas, Sara Jahanmir

We study the joint optimal production and pricing of innovations in markets where consumers' willingness to pay varies across time among different adopter categories. We model the production activities through the well-known dynamic lot sizing problem (LSP). In general, the demand is assumed to be known when addressing the LSP, however, in order to capture marketing/operations interactions, we assume a price sensitive demand, which diffusion depends on a Generalized Bass Model (GBM) for discrete horizons.

Even though we can combine LSP and GBM for synchronizing marketing/production decisions, the complexity of the corresponding problem increase due to two main issues: the combination of pricing decisions together with a LSP, and since the GBM should consider the changes on the willingness to pay of potential customers across the time, the demand for a product depends on the current price and on the previous ones.

4 - Designing the Spare Parts Supply Chain Network Under the (R, S) Inventory Control Policy
Francisco J. Tapia-Ubeda, Pablo A. Miranda, Gabriel Gutiérrez-Jarpa

Spare parts are crucial in order to ensure the continuity of the productive processes in several relevant industries. The Spare Parts Management problem comprises all the Spare Parts-related decisions from purchase to the consumption. The underlying Spare Parts Supply Chain Network supports the entire operation and must be designed and planned to reduce the unexpected downtimes and to be cost-efficient. Consequently, the design and control of the Spare Parts Supply Chain Network affect the company performance and results. Recent literature makes use of Inventory Location models considering different inventory control policies to design the Spare Parts Supply Chain Network. With this aim, a novel Inventory Location Model that integrate location and inventory control decisions to design the Spare Parts Supply Chain Network under the (R, S) inventory control policy, which is widely employed to manage Spare Parts. Thus, the proposed model can be applied to a great variety of industrial settings. Additionally, a Generalized Benders Decomposition-based solution approach is proposed and implemented. Despite the mathematical complexity of the model, the proposed solution strategy exploits the model structure for addressing the nonlinearity of the model. Some promising preliminary numerical results are shown.

■ WD-28

Wednesday, 14:30-16:00 - G102

Strategic and Dynamic Aspects

Stream: Operational Research in Financial and Management Accounting
Invited session
Chair: Sascha H. Moells

1 - Innovation Speed under Uncertainty and Competition
Gordon Briest, Elmar Lukas, Sascha H. Moells

Innovation speed is a key factor for a firms ability to maintain its competitive advantage. In this paper we propose a comprehensive model of the complete innovation process to study innovation speed and how it is influenced by uncertainty. We model the R&D phase on a par with the market phase. The former is modelled as sequential investment model related to Majd and Pindyck (1987). The latter is a complex extension of the market entry and exit model introduced by Dixit (1989). In both, we use a jump diffusion process to account for the dynamics of the state variable earnings. We further introduce the five forces by Porter (1979) as parameters to the market phase. Therewith the paper bridges the strategic management literature with real options literature in a novel way to study the impact of uncertainty and competition on innovation speed.

2 - Optimal feedback control of cash balance dynamics via linear programming
Amit Bhaya, Eugenius Kaszkurewicz

The classical cash balance problem of optimizing working capital in the short term is formulated as a discrete-time optimal control problem of maximizing final wealth, which is the total capital in the cash and investment accounts, over a finite horizon, subject to nonnegativity constraints and the standard dynamics of cash flow, including transaction or transfer costs, between the two accounts. Given a cash flow stream to the cash account (positive, if it is a payment to be made; negative, if it is a deposit), it is shown that the optimal control problem can be reformulated and solved as a linear program, furnishing the optimal sequence of transfers from the cash to the investment account and vice-versa. To improve on this open-loop solution, which also requires prior knowledge of the cash flow demand stream, it is shown next that the classical Miller-Orr three level threshold control policy that generates a (suboptimal) sequence of transfers, can be simplified to a closed-loop controller based on a single threshold or target level, which, moreover, can also be formulated as a linear programming problem, for a given target and cash flow demand stream. An output feedback control policy that determines cash transfers based only on the current cash flow demand and cash balance, by maintaining the latter at zero, is shown to be optimal. A myopic control approach, which uses current data to optimize final wealth, is also shown to lead to the same result.

3 - The impact of input market dynamics on the accuracy of costing systems over time
Ana Mickovic

The objective of this paper is to investigate factors that determine the size of errors in dynamic costing systems. The research method is quantitative and based on numerical simulation. Previous research on costing system accuracy has focused on measurement, aggregation and specification errors in static simulations. We build on that research and observe how adding a time-component influences the costing systems.

Specifically, we focus on costing systems with resources with particularly complex purchase price structure. In order to observe the effect these characteristics have on errors, it is not enough to observe costing systems at one time point. Instead, it is important to take into account their time properties. Because of that, we introduce the term dynamic activity-based costing.

■ WD-29

Wednesday, 14:30-16:00 - C118

Governance Analytics 2

Stream: Governance Analytics
Invited session
Chair: *Elise del Rosario*
Chair: *Cathal MacSwiney Brugha*

1 - Designing Framework Agreements: A Field Study in Government Procurement
Eduardo Lara, Daniela Saban, Marcelo Olivares, Gabriel Weintraub

Framework Agreements (FA) is a commonly used procurement mechanism by governments and large organizations. It is based on an auction-type design to select an assortment of products from multiple suppliers with posted prices, allowing some flexibility and variety to purchasing units. The design of FA requires balancing competition to enter the market with the variety offered inside the market. This paper conducts an empirical study of the FAs used by the Chilean government, identifying inefficiencies in the procurement market, providing improvements to design and conducting a field study to measure the actual effectiveness of the new implemented design.

2 - A study on the collaboration between research institutes with quantitative approach; focusing on government-funded research institutes
Yoon Been Lee

Since 1966, government-funded research institutes have played an important role in the national research innovation curriculum with universities and corporate. In the process of evolution and reorganization, they have been in the midst of system change in order not only to improve accountability and transparency, but also to find a balance point between stability and competition. Although there are various problems such as role overlap or insufficient efficiency, government-funded research institutes constitute the largest part of government research and development investment. It is necessary to grasp an objective detail of the situation in order to support discussion and narrow down diverse alternatives. In this study, we analyzed the type of research cooperation of government-funded research institutes from the viewpoint of quantitative analysis. The density of research cooperation network was very low, and there was a difference in the degree of cooperative relations by institution. In terms of each technology field, it was confirmed that there is a difference in the cooperative network structure which comes from maturity of technology or industry system. Therefore, it is necessary to make efforts to utilize the merits of the research institutes, which can conduct systematic research based on the solid organization and the field specialty, through launching of big projects that require large-scale cooperation of diverse technology fields.

3 - OR in Governance: Project Failures and Successes
Elise del Rosario

This presentation shares lessons learned in the process of undertaking several projects for various agencies in a developing country setting. Lessons learned from the project successes and failures will be shared. Important factors that played a role in the phases of the project life - analysis, design, implementation, and use- will be highlighted.

■ WD-30

Wednesday, 14:30-16:00 - C007

OR in Neuroscience

Stream: OR in Neuroscience
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Ulrike Leopold-Wildburger*
Chair: *Suryati Sitepu*

1 - A model of sex and trait anxiety differences as modified by environment in a novel situation using immunohistochemical and AI methodologies.
Nina Kajiji, Gordon Dash, S Tiffany Donaldson

In recent years research continues towards perfecting the next generation intelligent machines that are capable of finding answers in unstructured data. Researchers have returned to the synergetic effect that the field of neuroscience and artificial intelligence (AI) bring to better understanding of the human decision making. In this paper, we conduct an animal experiment on trait-bred Long Evans rats. Following acute exposure to the open field novel stress test and a dose of amphetamine we measure neural activation along the reward and fear circuitry by capturing c-fos levels in seven left-and-right brain regions. After establishing group mean differences via MANOVA we seek to confirm the parametric model results using an AI-based model. Our aim is to test whether environment, sex, and trait tend to mediate drug-induced hyperactivity. This research has direct bearing on how to best understand the chemical reaction in the brain of these animals as they transfer their learned behavior to a novel environment. We find that sex effect is most evident in the episodic, working, and continual memory regions. Both trait and environment dominate the working and continual memory regions.

2 - Simulation of Bribes, Detection Probability, Principal Witness Policy
Ulrike Leopold-Wildburger

While Operations Research represents the field of a science for delivering better decisions using optimal (or nearly-optimal) solutions for complex decision-making problems our behavior in reality quite often has to deal with non-fully rational decision makers. We will work on the tension between the two scopes by this research and we will show a specific example. Coming from the field of OR we are aware that that techniques such as mathematical modeling, statistical analysis, and mathematical optimization are engaged in applications of advanced analytical methods with the aim to make better decisions. However, in everyday life OR is often connected with other fields and disciplines, as psychology and behavioral sciences, even integrating neuroscience and microeconomics.

An example from the field of game theory will be prepared and checked with the actual behavior of decision makers in an specific situation. We will deal with the topic of fairness and honesty and we compare theoretical concepts with empirical data. The background idea is economic damage caused by corruption. We will present results from an experimental study on simulation of bribes, and our results refer to detection probability and the effects of a principal witness policy. It is interesting to see both sides of the deal: the willingness to offer respectively the willingness to accept bribes. Further, we are able to show that the possibility of whistleblowing does cause surprising results.

3 - Maximum Likelihood Estimation: Recent Developments
Michael Fu

We summarize some recent developments on maximum likelihood estimation (MLE) problems in settings where the likelihood function is non-convex with multiple extrema or the likelihood function cannot be easily evaluated, whether in closed analytical form or numerically, but a stochastic (causal) model of the system can be simulated. The first setting arises in many practical applications, but we are specifically motivated by the need to model the dynamics and statistical characteristics of brain activity based on measurement data from magnetoencephalography (MEG) and electroencelphalography (EEG). The resulting MLE problems require new approaches from global optimization such as model reference adaptive search (MRAS). In the other setting, the likelihood function must be estimated in an indirect manner via simulation of a stochastic model, e.g., a large queueing network, and we propose to apply recent results on a new direct gradient estimation technique called the generalized likelihood ratio method. Results reported are based on several different projects representing joint work with Yijie Peng, Bernd Heidergott, Henry Lam, Behtash Babadi, Yunchuan Li, Sina Miran, Steve Marcus, and Jonathan Simon.

■ WD-31

Wednesday, 14:30-16:00 - G108

Kidney exchange programmes (COST ACTION 15210 ENC KEP)

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Joel Joris Van de Klundert*

1 - UK Living Kidney Sharing Scheme
Matthew Robb

There are nearly 5000 patients in need of a kidney transplant in the UK currently. The average waiting time for a deceased donor kidney is over 2 years. This can be much longer in difficult to match patients. Over this period the health of the patient deteriorates further. If a patient has a willing living donor, either a relative, friend or partner, this eliminates waiting time. However, in many cases even if a patient has a willing living donor a transplant may not go ahead due to a blood group or tissue type incompatibility. The UK Living Kidney Sharing Scheme was set up in 2007 and gives patients with a willing but incompatible living donor an additional route to get a transplant. This allows donor-patient pairs to enter a quarterly 'matching run' that looks at possible exchanges between the donor of one pair and the patient in another to facilitate transplants for both patients. All possible matches are calculated and transplants are identified using an optimisation algorithm developed in collaboration with the University of Glasgow. This algorithm maximises the total number of transplants in line with criteria developed with the transplant community. Over 2400 donor-patient pairs have now entered the scheme and this has helped facilitate over 950 transplants which would otherwise not have been possible. Simulation work has also enabled development of a patient tool to give patients more information on their expected chance of transplant through the scheme.

2 - IP Solutions for International Kidney Exchange Programmes
Radu Stefan Mincu, Peter Biro, Márton Gyetvai, Alexandru Popa, Utkarsh Verma

In kidney exchange programmes patients with end-stage renal failure may exchange their willing, but incompatible living donors among each other. National kidney exchange programmes are in operation in ten European countries, and some of them have already conducted international exchanges through regulated collaborations. The exchanges are selected in regular matching runs (typically in every three months) according to well-defined constraints and optimisation criteria, which may differ across countries. In this work we give integer programming formulations for solving international kidney exchange problems, where the optimisation goals and constraints may be different in the participating countries and various feasibility criteria may apply for the international cycles and chains. We also conduct simulations showing the long-run effects of international collaborations for different pools and under various national restrictions and objectives.

3 - The health value created by Altrustic donation in Kidney Exchange Programs
Joel Joris Van de Klundert

Our research presents an analysis of the optimization problem to maximize the health benefits for patients suffering from end stage renal disease from including altruistic donors in Kidney Exchange Programs. Traditionally. Kidney Exchange programs are restricted to including patient-donor pairs, and exchange donors between patients. Altruistic donors are donors who volunteer to donate a kidney, without being paired to a patient on beforehand. To optimize the benefits gained, we propose a novel optimization model, which focuses on maximizing expected health value when solving the allocation problem arising in kidney exchanges. To evaluate the long run effectivess it is embedded in a discrete even simulation. Our computational results are based on complete data from a decade of kidney exchange in the Netherlands, the worlds longest standing national program.

4 - Fair Liver Transplant Allocation: A Scalable Optimization Model
S. Raghavan, Shubham Akshat, Sommer Gentry

The United States Department of Health and Human Services is interested in increasing geographic equity in liver transplants. We develop an optimization model to improve upon the current allocation system. Our model reduces the supply to demand variations among proposed allocation geographies and is scalable to a zip-code level. We compare our allocations against others via simulation.

■ WD-32

Wednesday, 14:30-16:00 - G109

Optimization Approaches for Complex Problems in Medicine

Stream: OR in Computational Biology, Bioinformatics and Medicine
Invited session
Chair: *Metin Türkay*
Chair: *Fatima Almaghrabi*

1 - An approach for solving challenges in a hospital network using stochastic programming
José Tomás Marquinez, Antoine Sauré, Sergio Maturana, Jonathan Patrick, Alejandro Cataldo, Max Andresen

Proper management in hospitals has a direct impact on patients' outcome, especially in some specific areas such as intensive care units or emergency departments. However, despite the efforts made by governments to deliver effective healthcare within their hospital network, this task has proven to be highly complex. One of the main determinants of this complexity is due to the uncertainty involved in the decision-making process on health policy and planning at any level. This uncertainty can be found starting at admission (how many will ask daily for medical assistance to each facility, what medical requirements will be needed, reason for consultation, the disease severity, etc.), or later in the diagnostic care process (how long will take their consultation, how long will be their length of stay in an inpatient bed, how long will the surgery take, etc.). To challenge these issues, describe the stochastic behaviors behind these processes, and support decision making, it is necessary to implement stochastic operations research techniques. The stochastic models developed in this research have shown to be useful to discover insights that better support making decisions in a hospital network. They have allowed us to make decisions regarding proactive transferences of ICU patients among different hospitals, about capacity expansion planning within the network, about patients' allocation in long term care facilities, among other healthcare-related decisions.

2 - GEDMod - Towards a Generic Toolkit for Emergency Department Modeling
Nikolaus Furian, Dietmar Neubacher, Cameron Walker

The design of generic models, or generic building blocks, for health care operations has been discussed in depth and identified as one of the grand challenges for researchers in the field of Modeling & Simulation. We provide an investigative basis for answering recently raised research questions for a specific sub-domain of health care facilities and a specific Modeling & Simulation paradigm, i.e. Discrete Event Models of Emergency Departments (EDs). Therefore, we perform a detailed analysis of a large set of published ED models. This analysis is executed following a structured conceptual modeling framework to ensure the coverage of all modeling aspects: objectives; input scenarios; output measures; structural components such as physical resources and human resources (including expertise and skill levels); patient classifications (arrival modes, triage grades, complaint categories); patient pathways including triage, treatment and admission phases; and organizational structures including control policies. The resulting collection and classification of modeling archetypes are used as the basis for an initial generic modeling toolkit for ED operations. Thereby, the modeler is guided through the main steps of conceptual modeling of Emergency Departments and generic building blocks for each step are provided. We conclude with a discussion on the applicability and benefits of the resulting framework along with the potential to combine the toolkit into a single generic ED model.

3 - A compartive sudy on feature selection for trauma outcomes prediction models
Fatima Almaghrabi, Dong-Ling Xu, Jian-Bo Yang

Various demographic and medical factors have been linked with mortality after suffering from traumatic injuries such as age and pre-injury comorbidities. A considerable amount of literature has been published on the building of trauma prediction models. However, few analyse the features selection criteria. Patient records comprise a large amount of data and numerous variables, and some are more important than others. Highlighting the most influential variables and their correlations would assist in the better use of them. The intention of this study is to clarify several aspects of demographic and medical factors that could affect the outcome of trauma in order to exhibit the interaction between these factors and to represent their relationships. In addition, the aim is to use ranking and weights of features to select the features that increase prediction accuracy and lead to better results. Keywords: feature selection, imbalance classes, random forest, evidential reasoning rule, ReliefF.

4 - Laboratory samples allocation problem
Diego Noceda, Maria Luisa Carpente, Silvia Lorenzo-Freire

This work aims to solve the optimization problem associated with the allocation of laboratory samples in plates. The processing of each of these plates is costly both in time and money, therefore the main objective is to minimize the number of plates used. The characteristics of the problem are reminiscent of the well-known bin packing problem, an NP-Hard problem that, although it is feasible to model as a linear programming problem, it cannot be solved at a reasonable cost. In this work, we propose a heuristic algorithm that provides good results with a low computational cost, outperforming state-of-the-art approaches.

■ WD-33

Wednesday, 14:30-16:00 - Q005

Economic modelling and game theory IV

Stream: Dynamics and Games
Invited session
Chair: *Alberto Pinto*
Chair: *José Martins*
Chair: *Bruno M.P. M. Oliveira*

1 - Offline retailers expanding online to compete with manufacturers: Strategies and channel power
Salma Karray

As traditional offline retailers complain about manufacturers' decision to compete with them by selling their products directly online, many are responding by starting their own online sales operations. This paper analytically examines when an offline retailer's expansion online is desirable and how it affects channel members' strategies and profits in a dual channel. We found that staying out of the online market when it is still not large enough or is extremely large could be a better alternative for an offline retailer. Otherwise, a retailer's online expansion cannibalizes offline sales, but increases the retailer's overall sales. It increases the retailer's channel power at the expense of the manufacturer, who continues however to have the lion's share of the channel profit. Depending on market conditions, the retailer may or may not set the same price across channels, while the manufacturer always sets a lower price than the retailer in the online channel. Finally, a price war across channels in a relatively large online market further reduces offline prices and can drive the retailer out of the offline market.

2 - University-firm competition in basic research and university funding policy
Mihkel Tombak, Rune Stenbacka

Abstract

We characterize equilibrium investments by the commercial and the university sectors contingent on public funding of the university. We find that the commercial sector invests in basic research despite the opportunities for free riding. We characterize the socially optimal volume of funding for the university sector. We compare the total equilibrium investment in a mixed duopoly with a public university competing against a for-profit firm with that of a duopoly composed of two profit-maximizing firms and find that the mixed duopoly invests more than the for-profit duopoly as long as the distortion of raising public funds is not excessively high. We also examine cases where the for-profit entity can fund the research in the university while maintaining its own research programme as well as cases with licensing.

3 - The use of game theory in modelling the process of creation and development of Smart Cities
Karolina Majdzinska, Robert Olszewski, Piotr Palka, Agnieszka Turek

A Smart City is a city where public issues are solved using ICT technologies with the involvement of many stakeholders working in cooperation with the city authorities. Analysis of the Smart Cities development needs to have defined groups of stakeholders and the potential and strength of the impact of various coalitions created by such entities as municipal authorities, citizens living or working in the city, entrepreneurs having a significant influence on decisions and media houses shaping public opinion. This issue can be effectively considered and modelled through the use of parameterizable cooperative games and various balance concepts such as core, least core, Shapley value, and nucleous. The research and numerical simulations carried out by the authors have shown that the key to solving the game is not only the number of entities involved (from micro, meso, and macro perspectives) but also their degree of independence in the decision-making processes and access to information. Interesting results are also obtained by comparing the development of smart city created from scratch and transformed by way of social and technological evolution. The research is interdisciplinary, and the results obtained may be of interest to specialists in spatial planning, urban planning, revitalisation, implementation of ICT, but also applied social sciences.

4 - Optimal strategies for international expansion with and without making dumping
Alberto Pinto, José Martins

In this work, we consider an economic model in which one firm has the monopoly of a certain market in its own country and divides another market in a foreign country with a firm of that foreign country. We study two possible strategies for the firm that is selling in both countries to increase its profit: the firm increases the production quantities to decrease the selling prices in both countries and avoid dumping; or the firm only increases the production quantity to decrease the selling price in the foreign country and makes dumping. To do our analysis we use a duopoly model and we characterize the parameters that define the most profitable repeated strategies. Acknowledgements: The authors thank the financial support of LIAAD-INESC TEC and FCT - Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within project Dynamics, optimization and modelling", with reference PTDC/MAT-NAN/6890/2014.

■ WD-34

Wednesday, 14:30-16:00 - Q006

Modelling and Optimisation in Cyber-commerce

Stream: Mathematical Modelling
Invited session
Chair: *Liming Liu*

1 - Enhancing Decision and Simulation Models of Cyber-Physical Production Systems Using Machine Learning

Cemalettin Ozturk, Deepak Mehta, Ali Azzam Naeem

Traditionally both decision-optimization and simulation models for production systems are designed and developed by a user based on his/her understanding of the system and the goal is to optimize several performance indicators. In the context of Industry 4.0, sensors and actuators are enabling the integration of cyber and physical world leading to cyber-physical production systems. This is resulting into a massive generation of data and creating opportunities for learning hidden relationships between system components unwritten rules. All models are abstraction of reality and hence there is a gap between the decision and simulation model, and similarly a gap between simulated system and the real system. Historically, decision and simulation models have been prescribed by a human user. Now, thanks to Industry 4.0 enablers, there is an opportunity to augment these models and to reduce the gaps between them using machine learning techniques. The challenge is how to update and steer these decision and simulation models continuously over time based on the relations learned by machine learning algorithms. This challenge also brings new opportunities for exploiting the full potential of emerging factories of future concepts like human-robot collaboration, Operator 4.0 and data driven manufacturing. In this presentation, we will review the current state of art and will provide some future research directions as well as preliminary results for proof of concept.

2 - Learning Decision Model for Detecting Malicious Activities

Andrea Balogh, Deepak Mehta, Alie El-Din Mady, Piotr Sobonski, Satyanarayana Vuppala

Advances in communications, sensors, and cloud computing has resulted in the proliferation of Internet of Things (IoT) which forms a foundation for Cyber-Physical Systems (CPS). Cyber-physical attacks aiming to disrupt the normal operations of the CPS which causes tangible effects in the physical world. The continued rise of cyber-attacks together with the evolving skills of the attackers, and inefficiency of the traditional security algorithms to defend against advanced attacks such as distributed denial of service and zero-day, necessitate the development of novel defense detection techniques compared to traditional approaches like signature and behavior-based methods. We propose a novel approach for learning detection model that includes operational, system, and network data to detect advanced attacks. Our approach is able to learn a relational network that connects events at different layers so that attacks can be identified with higher confidence level. We propose an approach for learning a constraint-programming (CP) based decision model by learning a set of constraints/relations from the data that conjunctively defines the normal operations of a CPS. The solutions of the decision model characterize the normal states of a given CPS. The malicious operations are detected when one or more constraints fails for a given state of CPS. The results demonstrates the effectiveness of the approach. The main advantage of our approach is the interpretability of the model.

3 - Big data and platform competition: The case of a multi-airport system

Amir Brudner, Riccardo Gallotti, Nicole Adler, Jose Ramasco

We utilize GPS records generated by mobile phones to estimate distance and ground access times to airports. Our analysis highlights the role of ground transportation and socio-demographic background of passengers in choosing between alternative airports. This brought us to the question which has arisen in the literature namely, do airports compete? This is significant because the answer is likely to impact the need to regulate airport charges. We present the methodology required to create the dataset which leads to a detailed catchment area analysis only available with Information and Communications Technologies (ICT) data. The data source which is used is mobile phone data and anonymized GPS data-points from which a trajectory to one of the six airports in the greater London area was formed. We than aggregate the behavior of anonymized users at the census level covering the whole of England and Wales. Subsequently, we develop a Hotelling style game in order to understand the behavior of producers (airlines and airports) and the likely impact on consumer surplus. We find strong potential for vertical collusion between an airline and an airport whereas horizontal collusion between airports is theoretically less likely. Fortunately, vertically collusive strategies contribute to consumer surplus as compared to horizontal collusion. Consequently, operational ICT data may be used by regulators and transport infrastructure planners to improve decision making at the strategic level.

■ WD-35

Wednesday, 14:30-16:00 - Q009

Scheduling problems in hospitals

Stream: Healthcare Logistics
Invited session
Chair: *Issam Nouaouri*
Chair: *Gilles Goncalves*
Chair: *Hamid Allaoui*

1 - A Two-Stage Transportation Problem for Healthcare Waste Management

Nasreddine Ouertani, Issam Nouaouri, Hajer Ben Romdhan, Hamid Allaoui, Saoussen Krichen

The healthcare waste transportation can expose handlers and the community to serious health risks if not managed under rules. This paper investigates the problem of healthcare waste management, with the intention of improving collection and transportation practices from hospitals to their waste treatment (or disposing) centers. The management process includes visits to a number of hospitals to collect waste, collection of waste from different medical cans in different points of the same hospital, loading them in the vehicle, then carrying them to the center. Therefore, the problem is modeled as a two-stage optimization problem where: the first stage is modeled as a Pickup Vehicle Routing Problem (PVRP) with the objective of minimizing the traveled distance between the depot and the visited hospitals, and the second one as a Travelling Salesman Problem (TSP) where the waste handler aims to minimize the travel time spent to pass through the different waste collection points. To solve this problem, a new hybrid evolutionary algorithm is proposed. The computational experiments showed the efficiency of the proposed method with regards to state of the art methods.

2 - Solution of a Large-Scale Assignment Problem: An application in the health care domain
Khouloud Dorgham, Issam Nouaouri, Hajer Ben Romdhan, Saoussen Krichen

The assignment problem, extensively studied in the combinatorial optimization literature, is known to be able to model and solve numerous real-world applications (e.g. production planning, transportation, healthcare, education, etc.). When adding the big data aspect, we can deal with a large scaled assignment problem. We propose in this paper an approximate approach, including heuristic and meta-heuristic algorithms specically designed to solve the assignment problem within a big data environment. The proposed approach is tested over well-known benchmarks and real-world case study. We show with a true deep experimental study, the effectiveness of our approximate approach in solving artificial instances and real case study related to the health care domain.

3 - Patient scheduling in emergency department
Issam Nouaouri, Seifeddine Abdelhak, Gilles Goncalves, Saoussen Krichen

The number of patients increases every year and a better resource management is needed. In this work, we introduce an analogy between patient scheduling and a flexible job shop problem in order to find the best patients sequencing and resource management. In patient scheduling environment, machines represent resources (doctor, nurse, X-ray, etc.) and patients represent jobs. The objective function is to minimize the patient waiting time. We developed a genetic algorithm to resolve first the classical job shop problem and we assess our approach on some benchmarks. The obtained results for the developed genetic algorithm we compare them with the best-known solutions for the Lawrence instances.

■ WD-36

Wednesday, 14:30-16:00 - Q010

Exact Methods for Vehicle Routing Problems II

Stream: Vehicle Routing and Logistics Optimization I
Invited session
Chair: Hatice Calik

1 - Compact formulations for the multi-depot routing problem
Daniel Santos, Luís Gouveia, Tolga Bektas

This talk will present compact formulations for the multi-depot routing problem (MDRP) defined on a directed graph in which the node set is partitioned into depots and clients. The aim is to find a minimum-cost set of circuits, where there exists one circuit for each depot and each client is visited in exactly one circuit. A feasible solution of the MDRP can be characterized by a set of disjoint circuits covering all nodes such that (i) each circuit contains at least one depot, and (ii) each circuit contains no more than one depot. Within mathematical formulations, condition (i) is generally represented by subtour elimination constraints, and condition (ii) is expressed by using so-called path elimination constraints. The compact formulations that will be presented in this talk are obtained by mixing and matching compact systems that model condition (i) using inequalities described in the earlier literature, and condition (ii) by making use of both existing and new inequalities. The formulations will be compared in terms of linear programming relaxation value, both theoretically and computationally, and on the basis of computational time requirements for attaining optimal solutions for a number of benchmark and randomly generated instances.

2 - A revisited branch-and-cut algorithm for the orienteering problem
Gorka Kobeaga, María Merino, Jose A. Lozano

The Orienteering Problem (OP) is a route optimization problem which consists in finding a simple cycle that maximizes the total collected profit subject to a maximum distance limitation. The occurrence of this problem in many real-life applications has boosted the emergence of many heuristic algorithms over the last decades. However, during the same period, not much effort has been devoted to the field of exact algorithms for the OP. In this talk, we will discuss the OP adaptation of some of the successful techniques for exactly solving the TSP.

In particular, we propose a branch-and-cut algorithm which includes the following novel procedures for the OP: safe shrinking for diverse separation templates, an adaptation for the OP of the separation algorithms for comb inequalities, efficient pricing, branching based on cliques and effective heuristics to convert fractional solutions to feasible OP solutions. Promising computational experiments show the importance of the proposed techniques and improvements.

3 - A mathematical programming approach to the vehicle routing problem with cargo safety and multi-drop constraints
Hatice Calik, Marc Juwet, Greet Vanden Berghe

The distribution companies serving multiple customers often do not dedicate different vehicles to different customers but rather combine their cargo (packages) inside the vehicles. This requires partial unloading of the packages at multiple drop-off points which might result in undesired empty spaces inside the containers or weight unbalances leading to security issues on the road. In order to achieve safer road transport, it is essential to properly secure the cargo inside the vehicle containers. In this work, we consider the vehicle routing problem with cargo safety and multi-drop restrictions. The demand of each customer should be delivered by a single visit. As unloading and reloading of packages is not allowed, the placement of the cargo inside the container should be arranged considering the order of visits to the customers. Moreover, the loading strategy should take into account the dynamic and static stability restrictions which must be ensured at every leg of the route for each vehicle. We propose an integrated mathematical programming approach that tackles the routing and loading decisions simultaneously to come up with an optimal strategy. We aim to minimize the total cost of routing and loading.

■ WD-37

Wednesday, 14:30-16:00 - Q011

Advances in Mirco and Macro Economic Modeling and Solution

Stream: Mathematical Models in Macro- and Microeconomics
Invited session
Chair: Burcu Gürbüz
Chair: *Olabode Adewoye*
Chair: *Alexander Vasin*

1 - Determination on punitive damages for online copyright infringement - game theory approach
I-Hsuan Hong, Pei-En Lai

The punitive damages are typically determined by the subjective judgement of legislators or designed on the basis of existing legal terms in the law in other countries. This study designs a mechanism to determine the punitive damage to optimize the total social welfare on the basis of the Stackelberg game, where the government is the leader and firms are followers. We take the piracy losses in the over the top (OTT) platform as an example to demonstrate the proposed model and analyze the performance among various objective functions of the government.

2 - On convexity and solution concepts in cooperative interval games
Jan Bok

Cooperative interval game is a special type of fuzzy cooperative game in which every coalition of players gets assigned some closed real interval. This generalizes classical cooperative games and models uncertainty about how much the members of a coalition get for cooperating together in a simple, yet quite practical way. In the talk, I will cover recent results on characterization of convex interval games, core coincidence problem, and axiomatization of the Shapley value for games with interval uncertainty. Our motivation to do so is twofold. First, we want to capture which properties are preserved when we generalize concepts from classical cooperative game theory to interval games. Second, since these generalizations can be done in different ways, mainly with regard to the resulting level of uncertainty, we try to compare them and show their relation to each other.

3 - Joint Effect of Liability Network and Portfolio Overlapping on Financial Systemic Risk: Contagion and Rescue
Shushang Zhu, Jiali Ma, Ying Wu

In this paper, we consider the systemic risk of a financial system where the financial institutions are connected by borrowing from/lending to each other while holding the same illiquid assets. By using an iterative algorithm, we prove the existence, continuity and other properties of the clearing payment vector and price vector. We also derive the concrete form of the joint effect of liability network and portfolio overlapping on financial systemic risk. We find that the inter-institutional liability connection and portfolio diversification can generally amplify the loss triggered by some shocks. Both the inter-institutional leverage of financial institutions and the illiquidity of assets are key factors that affect the financial risk contagion. Based on the theoretical findings, we propose a rescue strategy via solving a series of linear programs. Our results clarify further the contagion channels and may shed light on the management of financial systemic risk.

■ WD-38

Wednesday, 14:30-16:00 - Q012

Urban an Territorial Planning in MCDA 2

Stream: Multiple Criteria Decision Aid
Invited session
Chair: *Francesca Abastante*
Chair: *Isabella Lami*

1 - Multi-criteria decision making model for advising farmers on farm reorientation
Uroš Rajkovič, Trajče Nikoloski, Vladislav Rajkovič, Andrej Udovč, Martin Pavlovič

Structural changes in the field of farming present great challenges for farmers. Farm reorientation is one of them. The problem is how to advise farmers on this issue. We have developed a multi-criteria model for assessing an existing farm for reorientation to horticulture. This example shows how farmers may be advised by the aid of an expert system with the capability to explain pro and cons for a specific farm. The model was developed by a team of experts using software DEXi and it was tested in different farming regions in Slovenia.

2 - Competing and complementary risks models in a valuation method from multi-quality index: a case study of farmland pricing in South-East Spain
Juana-Maria Vivo-Molina, Manuel Franco

The asset valuation plays an important role in the economic areas. Specific valuation methods are required for estimating the market value under uncertainty when the information is not enough due to the lack of clarity in the prices of some markets. Farmland transactions are generally not recurring actions for most buyers and sellers, being often required reliable information from expert judgements. This paper shows how the competing and complementary risks models can assist in farmland pricing under uncertainty using a multi-quality index provided by expert-criteria. This approach overcomes some disadvantages of standard appraisal methods when the information is not enough, providing boundaries and more relative accurate assessments. The usefulness of these risks models is illustrated through an empirical application of farmland pricing by using a two-dimensional quality index, for comparison with its previous valuations reported in the literature.

3 - Evaluating energy retrofit projects at the building/urban scale: a methodology based on the Strategic Choice Approach and Life Cycle analyses
Diana Rolando, Elena Fregonara

The study proposes the use of MCDA for supporting decision-making processes in the context of energy retrofit projects related to existent buildings at the district/urban scale. The aim is to identify the preferable energy retrofit design solutions for energy-efficient buildings, sustainable from both environmental and economic viewpoint. The proposed methodology is based on the integration of two approaches. The first approach, assuming a Life Cycle perspective, is based on a joint application of Life Cycle Costing (LCC, ISO 15686-5:2008) and Life Cycle Analysis (LCA, ISO 14040:2006). The second one is the Strategic Choice Approach (SCA), a problem structuring method able to manage processes characterized by high complexity and uncertainty, and to design, compare and evaluate compatible decision options. Particularly, the results of economic and environmental analysis developed by means of LCC and LCA are included as Comparison areas in order to assess alternative energy retrofit technological options. An application of the methodology is presented assuming a reference building in Turin (Northern Italy), representative of the building construction techniques that mostly need to be refurbished. First findings demonstrate how designers, constructors, developers and public authorities can be supported in decision-making processes, since the early design stages, in order to reduce energy consumptions at building level, and, consequently, at district/urban level.

■ WD-39

Wednesday, 14:30-16:00 - Q014

Moments in History of OR: Ireland

Stream: Moments in History of OR
Invited session
Chair: *Cathal MacSwiney Brugha*

1 - The life and contribution of William Sealy Gosset: Student's t-test brewed at Guinness
Graham Rand

The t-test, used, for example, to determine if two sets of data are significantly different from each other, was developed by W S Gosset in 1908, when he was a chemist working for the Guinness brewery in Dublin. It is known as Student's t-test because Guinness did not allow its chemists to publish their findings, so Gosset published his statistical work under the pseudonym "Student". However, Guinness did allow technical staff to have "study leave", which Gosset had used during the first two terms of the 1906-1907 academic year in Professor Karl Pearson's Biometric Laboratory at University College London. His identity was therefore known to fellow statisticians. This presentation will summarise his life and times, and his statistical contributions, drawing on appreciations published in Biometrika after his death in 1937.

2 - Ireland's Journey from OR to Analytics
Cathal MacSwiney Brugha

The Operations Research Society of Ireland was founded in 1964, and in 1972 the ORSI hosted one of the first IFORS conferences in Trinity College Dublin (TCD). At this conference the decision to set up EURO was taken, the Association of European Operational Research Societies. In the 1970s Operational Research became part of the curriculum in University College Dublin's Business School. A Department of Management Information Systems was formed in 1979, and established a Master of Management Science degree. From the beginning it included dissertations, combining the technical skills of the students into applications such as routing, airline booking, and multi-criteria decision-making. Subsequently a Research Centre was developed. As time went on, the terms Operational Research and Management Science did not capture sufficient interest. Both the Centre and the Masters programme were re-named and re-focused as Business Analytics. Members of the department have included the first professor in the area, Harry Harrison, who won the Franz Edelman Award in 1978 for an application in pharmaceutical distribution; Cathal MacSwiney Brugha, President of the Analytics Society of Ireland, who was for some years Editor of International Transactions in OR, the IFORS journal; and Seán McGarraghy, Chair of the Organising Committee of EURO2019. Members of the Society also include Fred Ridgeway, an organiser of IFORS 1972, and Roy Johnston, former President of Irish OR Society.

■ WD-41

Wednesday, 14:30-16:00 - Q013

Robust Optimization in Metro and Railway Systems

Stream: Public Transportation I
Invited session
Chair: *Valentina Cacchiani*

1 - Robust Optimisation for Periodic Railway Timetabling
Gabor Maroti, Gert-Jaap Polinder, Thomas Breugem, Twan Dollevoet

We study the periodic railway timetabling problem. We want to determine the departure and arrival times in such a way that all underlying technical constraints are satisfied an that the total travel times are minimised.

This research considers an adjustable robust timetabling problem: we consider a (parametrised) uncertainty region, and we require that the nominal timetable's feasibility be recoverable within a limited recovery budget no matter which disturbance scenario is chosen from the uncertainty region. The uncertainty parameter governs the severity of the disturbance.

We propose a solution method by combining a linear decision rule with well-known reformulation techniques and cutting-plane methods. We demonstrate the power of our approach by solving for practical-sized instances by applying the solution method to practical cases of Netherlands Railways (NS). Our methods enable us to study the intricate trade-off between the solution's efficiency, on on hand, and its robustness, on the other hand.

2 - Light Robustness for Handling Passenger Demand Uncertainty in Integrated Train Stop Planning and Timetabling
Valentina Cacchiani, Jianguo Qi, Lixing Yang

We study the problem of determining the schedule and stop pattern for a set of trains in a railway line, when passenger demand is uncertain. Passenger demand fluctuation can lead to overcrowded trains or even unsatisfied demand, causing passenger discomfort. We aim at determining robust solutions against this uncertainty, by finding a stop plan and a train schedule that can cope with different demand scenarios. We propose Mixed Integer Linear Programming (MILP) models based on the technique of Light Robustness, in which uncertainty is handled by inserting a desired protection level against increased demand, and efficiency is guaranteed by limiting the travel time and the number of train stops. The proposed models differ in the way of inserting protection, and require different information about passenger demand. We test these models on real-life data of the Wuhan-Guangzhou high-speed railway line under different demand scenarios.

3 - Robust Passenger Flow Control on Oversaturated Metro Lines: A stochastic Optimization Method
Lixing Yang, Fanting Meng, Jungang Shi

With the rapid increase of travel demands in urban areas, the overloaded passenger flow has become a normal phenomenon in the metro system of some large cities. Once the number of passengers on a platform exceeds its capacity, it is inevitably to cause operation risks due to the space limitation. To guarantee the safety and improve the operational efficiency, this paper proposes an effective method to generate a robust passengers flow control strategy over a metro line with the predetermined train timetable, in which the stochastic and dynamic passenger flow is specifically taken into consideration. By discretizing the time horizon into a series of timestamps, we formulate an integer linear programming model with the objective of minimizing the expected passenger waiting time on the whole metro line, in which scenario-based data representation is used to characterize the dynamics of passenger demands. To solve the proposed model, a heuristic algorithm, which integrates the Lagrange relaxation approach and CPLEX solver, is designed to search for high-quality solutions for the problem of interest. Finally, two sets of numerical experiments, including a small-scale case and a real-world instance with operation data of Beijing Batong metro line, are implemented to demonstrate the performance of the proposed approaches.

4 - Dynamic train timetabling with uncertain passenger characteristics: Mathematical model and real-time solution algorithms
Jiateng Yin, Lixing Yang, Andrea D'Ariano

Considering the uncertainty of passengers' behaviors (i.e., transport mode and route choice), our study first proposes a two-stage stochastic programming model that aims to generate a robust train timetable dynamically for minimizing the passengers' inconvenience under disruptions. In our model, the first stage aims to generate the robust train timetable while the second stage model considers the passengers' travel behaviors under each stochastic scenario. Using discrete sampling approximations, the model can be transformed into mixed-integer linear programming. Even though it is able to be handled by exact algorithms e.g., branch-and-bound or cutting plane, the computational intensity is high that cannot meet the time requirement in practical implementations. To this end, our study proposes a Benders' decomposition framework to decompose the original problem into a master problem (MP) and a set of sub-problems (SPs). In particular, each sub-problem corresponds to the passenger flow assignment problem under each discrete sample, which can be efficiently solved by a column generation method. We code our algorithms by C++ in a VS environment. With the aid designed solution approaches implemented and parallel computing, our algorithm allows to make changes to the working timetable in near-real time. Numerical experiments are conducted to verify the effectiveness of the proposed approach.

■ WD-43

Wednesday, 14:30-16:00 - Q114

Game Theory and Management

Stream: Frontiers of Dynamic Games and Management
Contributed session
Chair: *Nikolay Zenkevich*
Chair: *Yaroslavna Pankratova*

1 - Pricing in public transportation networks with externalities
Vladimir Mazalov

We consider a network comprised of parallel routes with the linear latency function and introduces externalities into the transportation network model. We analytically derive a system of equations defining the optimal distribution of the incoming flow with minimum social costs, as well as a corresponding system of equations for the Wardrop equilibrium in this network. In particular, the Wardrop equilibrium is applied to the competition model with rational consumers who choose the carriers with minimal cost, where the cost is equal to the price for service plus the waiting time for service. We evaluate the price of anarchy and show that for some levels of externalities the social cost in equilibrium coincides with the optimal social cost.

2 - Coordinating contracts in distribution supply networks
Natalia Nikolchenko, Nikolay Zenkevich

The relationships between companies in supply networks leads to a decision-making process of multiple entities, regardless of contracts or other binding agreements. Coordination with contracts enables aligning supply network members' objectives [1], maintaining the decentralized decision-making conditions, and motivates companies to cooperate for achieving results close to centralized network. Thus, game theory seems to provide an adequate basis for modeling of interaction between players. For the purpose of the research the contract is said to coordinate supply network if the individual and collective rationality properties are fulfilled. This means that such a contract must be a Nash equilibrium in the considering model, and possesses a Pareto-optimality property [1]. This research explores a distribution network where agents are connected in some network relationship. The study is aimed to show the role of contracting mechanism in achieving coordination in distribution networks and investigates cooperative multi-echelon game involving manufacturer, distributor and retailers. The game solution is the optimal parameters of the contract in terms of network coordination. The multi-echelon network model with revenue-sharing contract is proposed. [1] Cachon, G., 2001. Supply chain coordination with contracts. In: Graves,S., Kok,T.D. (Eds.), Handbooks in Op. Res. and Manag. Sc.: SCM. N-H, Philadelphia PA, 1-95.

3 - Coordinated influence on the beliefs of social network members
Artem Sedakov

Mikhail Rogov and Artem Sedakov (Saint Petersburg State University)

We examine a model of the coordinated influence in a social network in which several its members, called players, can jointly influence the beliefs of other members, called agents, during a finite number of periods. The model is considered as a cooperative dynamic game. The influence of players is expressed by declaring their beliefs which are then considered and weighted by the agents to form their own beliefs. Our goal is to find the declared beliefs of players focusing only on associated costs as well as on the average deviation of agents beliefs from the desired ones. Under coordination, the total costs of players are allocated using the Shapley value. When we have no information regarding the levels of trust for agents to each other, we estimate these values by means of a centrality measure. Numerical simulation is carried out for a well-known social network of a university karate club and for a lattice often used for modeling spatial networks.

4 - The SM-nucleolus in bi-cooperative games
Yaroslavna Pankratova, Svetlana Tarashnina

In the present paper, we introduce a new solution concept, the simplified modified nucleolus or the SM-nucleolus, for a bi-cooperative game. Bi-cooperative games were introduced by Bilbao et al. [1] as a generalization of TU-cooperative games. The simplified modified nucleolus is based on the idea of the modified nucleolus (the modiclus [3]) and takes into account both the constructive power and the blocking power of a coalition [4]. First we ex-tend a notion of an excess, a duel game and a sum-excess for bi-cooperative games, and define the SM-nucleolus. On top of this, we give several examples that illustrate similarities and differences between the SM-nucleolus and the Shapley value [2] for bi-cooperative games.

1. Bilbao JM, Fernandez JR, Jiménez Losada A, Lebrón E (2000) Bicooperative games. In: Bilbao JM (ed) Cooperative games on combinatorial structures. Kluwer, Dordrecht. p. 131-295.

2. Bilbao JM, Fernández JR, Jiménez N, López JJ. (2007) The Shapley value for bicooperative games Annals of Operations Research, 158(1), p. 99-115.

3. Sudhölter P (1997) The modified nucleolus: properties and axiomatizations. Int J Game Theory 26, p. 147- 182.

4. Tarashnina, S. (2011) The simplified modified nucleolus of a coopera-tive TUgame, TOP, 19(1), p. 150-166.

■ WD-45

Wednesday, 14:30-16:00 - Q117

Electric Vehicle Charging

Stream: Green Logistics
Invited session
Chair: *Maximilian Schiffer*
Chair: *Gerhard Hiermann*
Chair: *Paul Göpfert*

1 - Location Planning for Dynamic Wireless Charging Systems for Electric Airport Service Vehicles
Justine Broihan

Dynamic wireless charging systems enable user-independent recharging of electric vehicles while they are in motion. A power transmitter embedded in the road establishes an electromagnetic field while vehicles equipped with pickup systems pass over the transmitter. The vehicle picks up the supplied electrical energy, and the battery is charged. A dynamic wireless charging system has been successfully installed on the Korea Advanced Institute of Science and Technology (KAIST) campus and in the Korean city of Gumi. Another possible area of application is the dynamic wireless charging of electric service vehicles on airport aprons. In this talk, a modelling approach for the strategic planning of a dynamically inductive charging infrastructure, which ensures a sufficient supply of energy for all service operations, is presented. The approach minimizes the infrastructure investments. In a numerical study, different instances are evaluated. A simulation validates the resulting infrastructures.

2 - Branch-price-and-cut for the electric vehicle routing problem with stochastic travel times and battery consumption chance-constraints
Alexandre Florio, Nabil Absi, Dominique Feillet

In this talk, we present a novel branch-price-and-cut (BP&C) algorithm for solving an electric VRP with stochastic travel-times and energy consumption. We model and solve the problem directly on the road network graph. This is motivated mainly due to (i) the difficulty of properly dealing with stochastic travel times in the customer-based graph, as pointed out recently in the literature, and (ii) the possibility, in the road network, of representing all the relevant attributes that can affect energy consumption when traveling along a road link.

The first contribution is a method for generating time- and space-correlated speed scenarios. This technique makes use of speed average and speed variance profiles defined on each link, which are then used to generate a multivariate normal distribution that represents the traveling speed on every link and time period. In addition to space- and time-correlation, the technique also enables time-dependency, much common in urban scenarios due to e.g. peak traffic hours.

Next, we introduce a BP&C algorithm to solve the target problem. The main difficulty when designing such algorithm is to develop an efficient procedure for checking the feasibility of routes, since the battery consumption constraint is probabilistic. By drawing and evaluating scenarios, we are able to statistically infer the feasibility (or infeasibility) of routes. This procedure is incorporated into the pricing algorithm.

3 - A Branch and Cut Approach to Electric Vehicle Recharging Infrastructure Planning
Paul Göpfert, Stefan Bock

In this talk we consider a Branch and Cut Approach for the determination of an efficient network of recharging stations for long distance traveling. The proposed Branch and Cut Approach provides a decomposition of the problem into a LP-Relaxation for the selection of stations and a graph algorithmic component that ensures a proper statement of demand coverage with respect to the selected stations. The additional problem specific consideration of zero-half-cuts further tightens the bounds on the objective value. A computational study shows, that our algorithm is powerful enough to solve the considered problem even on realistically sized networks. An exclusive focus on long distance demands is shown to lead to a significant increase in computation times.

■ WD-47

Wednesday, 14:30-16:00 - L247

Nonsmooth optimization and applications 2

Stream: Continuous and Black Box Optimization
Invited session
Chair: *Giovanni Giallombardo*

1 - Dual ascent methods for directional sensor networks
Giovanna Miglionico, Annabella Astorino, Manlio Gaudioso

Wireless sensor network problems have received great interest in last years since they impact on a number of diverse application fields such as security, healthcare and environment. We focus on two of the most studied sensor network optimization problems, i.e. the Sensor Coverage Problem (SCP) and the Network Lifetime Problem (NLP). In our setting the sensors are directional and hence characterized by a discrete set of possible radii and aperture angles. The SCP problem aims at activating the minimum number of devices so that each target of a given area of interest is sensed by at least one sensor. As for NLP, the objective is to define an appropriate scheduling and setting of the sensors to maximize the time when all targets are covered. The novelty of our approach is in the extensive use of Lagrangian relaxation as an effective decomposition tool for adopted models, that fall in the class of MINLP (Mixed Integer Nonlinear Problems). We design ad hoc dual ascent procedures for the (nonsmooth) Lagrangian duals, which are equipped by Lagrangian heuristics. The results obtained by implementing our methods are also presented.

2 - LMBM-Clust, the nonsmooth optimization approach for clustering large data sets
Napsu Karmitsa, Adil Bagirov, Sona Taheri

Clustering is among most important tasks in data mining and knowledge discovery in databases. The problem of clustering in large data sets is challenging for most existing clustering algorithms. Here we present an algorithm based on nonsmooth optimization technique to solve the minimum sum-of-squares clustering problems in very large data sets. First, the clustering problem is formulated as a nonsmooth optimization problem. Then the nonsmooth optimization algorithm, the limited memory bundle method [Haarala et.al. Math. Prog., Vol. 109, No. 1, pp. 181-205, 2007], is modified and combined with an incremental approach to design a new clustering algorithm. The new algorithm is evaluated using real world data sets with both the large number of features and the large number of data points. It is also compared with some other optimization based clustering algorithms. The numerical results demonstrate the efficiency of the proposed algorithm for clustering in very large data sets.

3 - Polyhedral separation approaches for pattern classification problems
Annabella Astorino, Antonio Fuduli, Manlio Gaudioso

In the last twenty years a remarkable research work has been performed in the area of data analysis and machine learning, mainly tackling problems of clustering and classification type. This work deals with pattern classification, which consists in categorizing data into different classes on the basis of their similarities.

From the mathematical point of view, classification reduces to finding separation surfaces in the sample space, where the objects (samples) are represented through their attributes. If the sets are linearly separable then one hyperplane provides complete separation, however, in many real-world applications, this is not the case. In most datasets, in fact, classes are disjoint but their convex hulls intersect. In this situation, the decision boundary between the classes is nonlinear and it can be approximated by using for example piecewise linear functions.

In this work we present some nonlinear models for classification problems of supervised, semisupervised and Multiple Instance Learning (MIL) type, by tackling polyhedral separation approaches.

■ WD-48

Wednesday, 14:30-16:00 - L248

OR Applications in Industry 2

Stream: OR Applications in Industry
Invited session
Chair: *Lukas Bach*
Chair: *Geir Hasle*
Chair: *Einar Aastveit*

1 - Capacity and source planning in the aluminium industry
Truls Flatberg, Michal Kaut

This talk will present how operations research models can be integrated in the sales, operations and capacity planning of a large, integrated aluminium company. With multiple production locations for primary aluminium and a global customer market, the company faces a complex problem both with regard to distribution and production planning. One of the challenges when introducing a decision support system is to ensure quality in the data flow. By moving parts of the optimization close to the individual sales and operations managers, we show how even fairly simple linear programming models can be used close to the sales planning and provide both ownership to the data and data consistency. These data are then aggregated and combined with data on production capacities and capabilities in a central model that provides decision support in the overall source and capacity planning.

2 - Ice Routing Problem in a Dynamic and Stochastic Environment, a Look-ahead Model
Mingyu Li, Peter Schütz

We discuss the problem of finding the optimal route for a ship sailing in ice. Sailing in ice, and especially in the Arctic, is often characterized by non-stationary ice conditions, poor quality of forecasts regarding these ice conditions and sometimes even a lack of data, introducing uncertainty into the problem. The problem can be formulated as a shortest path problem with uncertain and time-dependent travel times. Our objective is to find the shortest expected travel time from the ship's current position to the destination, but alternative objectives are also under consideration. These objectives include minimizing the cost of the voyage (including the ship's operational costs, but also the cost of icebreaker assistance), minimizing the environmental footprint of the voyage and minimizing the risk of damage to the vessel (e.g. based on the Polaris risk indicator). We consider a planning horizon of 15 to 20 days, with new ice information becoming available in regular intervals during the voyage. Decisions should therefore be reconsidered each time information is received. We present the look-ahead model formulation, a solution method based on stochastic dynamic programming as well as some preliminary results.

3 - Scheduling observations on the Very Large Telescope
Florian Fontan, Pierre Lemaire, Nadia Brauner

Large telescopes are few and observing time is a precious resource, while more and more astronomical projects require a significant number of observations to be done during dis-continuous periods spread over several months or years. In this context, Catusse et al. (2016) proposed an exact algorithm to schedule observations on a telescope during a given number of nights, the objective being to maximize the sum of the weighted number of observations (the weight of an observation corresponding to its scientific interest). However, the model must be refined to provide more applicable solutions.

Currently, observation times are fixed to their maximum value (observing longer would not result in a better picture) but in practice the observation time of a star may be reduced, downgrading the quality of this observation, but potentially making room for additional ones. Other model extensions include: mandatory observations, durations that depend on the start date of the observation, weights that depend on both the observation and the night (to handle emergencies), and some other more exotic aspects.

Here, we propose a local search algorithm that has been implemented in the software used by the astrophysicists, and we study its experimental performances. This algorithm handles all the constraints of the problem and still performs very well on the instances of the previous (less general) model.

4 - Optimal Clearing Algorithms for Pan-National Electricity Reserve Markets - Experiences from the Nordics
Einar Aastveit, Gavin Bell, Magnus Hausken

Power system operation requires that demand equals supply at all times. Demand and supply imbalance can result in grid instability or severe voltage fluctuations, and cause failures within the grid. Imbalance management is an essential role of transmission system operators (TSOs). To do this, TSOs use flexible production and consumption resources, called system or power "reserves", to alter production or consumption levels in near-real-time. Traditionally, TSOs have obtained reserves via directly contracting with the operators of production assets or large consumers. However technological and regulatory developments are resulting in a move to the use of markets to obtain reserves more efficiently. Here we report on the development of clearing algorithms for three reserve markets for the Nordic synchronous grid. The markets are characterized by a complex set of requirements including structured bids, rules for transmission between areas, varying national- and pan-Nordic clearing rules, and different pricing methodologies between the Nordic countries. Our approach has been to model these markets as mixed integer programs, or a sequence of mixed integer programs where these complications require the decomposition into linked sub-problems. Variations on the clearing algorithms are also used to determine cleared market prices. The algorithms are currently undergoing acceptance testing and are expected to go live during 2019.

■ WD-49

Wednesday, 14:30-16:00 - L249

Dynamical Models in Sustainable Development III

Stream: Dynamical Models in Sustainable Development
Invited session
Chair: Andreas Felsberger

1 - Evaluation of farmers' response to implementing buffer strips to control soil erosion using agent-based modeling in Chile
Prajna K A, Bruno Morales, Jörg Dietrich, Jose Luis Arumi

Soil erosion is a severe problem in Chile that affects agricultural production. According to UNEP's report on Chile, wheat production faces a serious problem with soil erosion. This study investigates behavioral changes in farmers from Bulnes, Chile to install vegetative filter strip in their fields to avoid soil losses due to erosion. In this, the farmers' behavior was studied and predicted based on the Theory of Planned Behavior (TPB). Farmers' behavior to make a decision is governed by the strength of intention (attitude, subjective norm, and perception of behavioral control); willingness to try; exert effort towards the task and environmental knowledge which have been analyzed from field survey. A five-point Likert scale is used in the survey. The sediment erosion that prompts behavior is modeled by VFSMOD-W, an event-based vegetative filter strip model. The farmers are modeled as agents in NetLogo with behavioral change utility function equations in accordance with TBP. NetLogo is linked to VFSMOD-W to trigger a change in agent behavior according to the amount of sediment erosion in a year. The findings are helpful to decision makers to understand farmers and develop feasible and efficient policies for implementation of buffer strips to reduce soil erosion and nutrients loss from agricultural fields. Thus, reducing soil and pollutant load in water bodies.

2 - Modelling agent behaviour in food systems
Seán McGarraghy, Rossen Kazakov, Ingunn Gudbrandsdottir, Gudrun Olafsdottir

Complexity arises in food supply chain systems from the points of view of managing fairness, sustainability and resilience, emerging out of agents interactions; this naturally suggests managing agent behaviour. The authors describe their approach to managing agents through the stages of mapping their behaviour and then simulation of intervention scenarios. This work is part of an EU-funded project on understanding food value chains. We report on initial work on developing a qualitative food system model of the Salmon supply chain market, applying a complex adaptive systems perspective. The paper focusses on the problem of fairness related to price setting and price distribution, and illustrates how techniques like cognitive mapping and agent behaviour mapping are used for system analysis and agent rules definition. The goal of this qualitative agent modelling approach is to support the conceptual, functional and technical specification for the quantitative modelling phase. To complement the above complex systems perspective, the authors have also applied concepts from stakeholder theory, resource dependence theory and behavioural decision theory, to create a more comprehensive picture of market agents' competitive behaviour.

3 - The impact of digital technologies on manufacturing performance: A system dynamics approach
Andreas Felsberger, Bernhard Oberegger, Boualem Rabta, Gerald Reiner

The purpose of this research is to analyze the impact of digital technologies on process quality and associated product quality that might increase the overall performance of manufacturing companies and supply chains. The implementation of digital technologies, such as smart factory systems or data science applications, represent an enabler for increasing competitiveness of manufacturing. The presented study will focus on the economic and social dimension of sustainability. For instance, installing additional sensors and business analytics applications promise to improve the capability of production processes. This might have a positive impact on lead times, process variability and cost reduction that may lead to increased customer satisfaction and customer retention. Moreover, these technologies may influence the transformation of work design and smart collaboration along manufacturing supply chains. Motivated by these potentially disruptive expectations, we develop a system dynamics model that analysis how the effects of fast-paced technologies cause fundamental challenges and opportunities for manufacturing companies and supply chains. The model integrates key performance indicators to evaluate the value creation through new technology implementation and unanticipated side effects on the above-mentioned sustainability dimensions. We intend to assess the effect of such digital technologies on organizations, financial performance and supply chain productivity.

■ WD-50

Wednesday, 14:30-16:00 - Mason Hayes & Curran

Understanding the practice of Problem Structuring Methods - III

Stream: Soft OR, Problem Structuring Methods
Invited session
Chair: *Ashley Carreras*

1 - Analysis of the impacts of organizational culture change applying Strategic Options Development and Analysis (SODA): a case study on a technology services company
Nissia Carvalho Rosa Bergiante, Thainá Moulin Maia

Organizational culture is a very particular characteristic of each company. It defines not only how everyday tasks will be executed but also the organizational environment and the way employees behave with each client. Keeping and maintaining it is a challenge for the company, but it gets even harder in a changing situation. In this context, this paper aims to define the challenges faced by companies that experience cultural change in their operations. To achieve it, it proposes the application of SODA methodology to understand the problematic situation that a Brazilian technology company has experienced and experiences nowadays through the coexistence of two organizational cultures, the agile and the business process management. The stakeholders were chosen according to the impact and influence they had during this change movement. The results of the interviews were analised in quali and quantitative ways. As a result, the paper explores the main problems in this process, clarifying the scenario to help the decision-making process and the managers planning. Some actions were proposed in order to manage this process, such as workshops sessions with associates from different teams to show the benefits e quick wins of the new culture and clarify the evaluation criteria.

2 - Improvement strategies to the procurement area in the industrial gases industry: a SODA approach
Paula da Cunha Felippe, Nissia Carvalho Rosa Bergiante

The competition for market share has driven companies to a continuous search for improvements, making the purchase area more strategic since its potential for cost reduction and efficiency increase. The buyer's role has evolved from a simple negotiation of unit prices to a company's strategic propositions, making the commonly used practices inefficient. In this context, this work analyzed the Procurement area of a multinational company in the sector of industrial gases and mapped improvement opportunities that could enhance its results. To do so, we applied Strategic Options Development and Analysis (SODA) method and performed qualitative and quantitative analysis based on data gathered from interviewers and on graph theory for better understanding the scenario and its complexity. As a result, we built a cognitive map and identified eight clusters (Overload, Supplier, User Relationship, Financial Results, Metrics, Compliance, Reliability and Team), which represent the main challenges faced by this area. Based on the centrality of the graph, we pointed out the trigger causes which are related to manage team workload and accumulation of operational activities, as well as issues related to an unprepared team, high number of single suppliers and a worn-out relationship with them. Finally, through centrality measures in the cluster analysis, we developed and prioritized strategies to optimize their resources to attain a higher level of performance.

3 - Embedding Problem Structuring Methodologies in Organisations: A case study
Ashley Carreras, Parmjit Kaur

This paper investigates the medium and long term impacts of two Causal Mapping workshops that focused on the strategic development of one large PLC and one Neighbourhood Association. We will report on how workshops impacted on each the organisations but also upon the use of the materials generated in the workshops and how they influenced the development of the organisations. The results will influence the recommendations we make to organisations, both on the use of the use and availability of the maps generated. We will also reflect on the advice we give in determining the suitability of the technique to be used in the specific organisational context.

■ WD-51

Wednesday, 14:30-16:00 - William Fry

Innovations in Supply Chain Network Models and Applications

Stream: Innovations in Supply Chain Network Models and Applications
Invited session
Chair: *Anna Nagurney*

1 - Sustainable, multiperiod supply chain network model with freight carrier through reduction in pollution stock
Sara Saberi

Sustainable supply chain management is a huge issue from both managerial and eco- nomical perspectives. This study presents a multiperiod, multitier, sustainable supply chain with freight carriers network model to address such concerns. The model comprises manufacturers, retailers, and carriers engaged in a dynamic, noncooperative game. It considers the longitudinal accumulation of pollution stock, pollution absorbtion by nature, and mitigation actions. The study examines numerical examples with an analysis of the effect of different tax rates on production, transportation, sales, and levels of pollution stock and mitigation efforts. The outcome presents important strategic reactions of decision makers to tax policies.

2 - Global Supply Chain Networks and Tariff Rate Quotas: Equilibrium Analysis with Application to Agricultural Trade
Anna Nagurney, Deniz Besik, Ladimer Nagurney

In this paper, we develop a global supply chain network model in which profit-maximizing firms engage in competition in the production and distribution of products in the presence of quantitative trade policy instruments in the form of tariff rate quotas. We construct the governing set of novel equilibrium conditions associated with the product flows and Lagrange multipliers, which correspond to quota rent equivalents, and derive the variational inequality formulation. Qualitative properties are presented along with an effective algorithm, which is then applied to compute solutions to numerical examples comprising an agricultural product case study on avocados and global trade.

3 - One-Sided Risk Sharing Contracts in Sustainable Supply Chains
Shivani Shukla

In this paper, we develop a framework that captures the effects risk sharing contracts in sustainable supply chain management. In particular, we analyze the impact of strategic sharing on supply chain disruption risks and costs and we evaluate the supply chain performance of risk sharing contracts. The numerical examples highlight that it is not a priori clear which participant in the supply chain network will benefit from increased information sharing activities. Our models indicate that the beneficiary of reduced information sharing costs is in some cases dependent on the negotiation power of participants and that it is also dependent on the type of risk sharing contract used. Furthermore, the numerical examples show that in some cases information sharing and risk sharing contracts are complements while in other cases they are substitutes.

Wednesday, 16:30-17:30

■ WE-01

Wednesday, 16:30-17:30 - O'Reilly Hall

Dick den Hertog

Stream: Plenaries
Plenary session
Chair: *Luís Gouveia*

1 - What every OR practitioner should know about Robust Optimization
Dick den Hertog

In this presentation we explain the core ideas in robust optimization and show how to successfully apply them in practice.

Real-life optimization problems often contain parameters that are uncertain, due to, e.g., estimation or implementation errors. The idea of robust optimization is to find a solution that is immune against these uncertainties. The last two decades efficient methods have been developed to find such robust solutions. The underlying idea is to formulate an uncertainty region for the uncertain parameters for which one would like to safeguard the solution. In the robust paradigm it is then required that the constraints should hold for all parameter values in this uncertainty region. It can be shown that, e.g., for linear programming, for the most important choices of the uncertainty region, the final problem can be reformulated as linear optimization or conic quadratic optimization problems, for which very efficient solvers are available nowadays. Robust Optimization is valuable for practice, since it can solve large-scale uncertain problems and it only requires crude information on the uncertain parameters. Some state-of-the-art modeling packages have already incorporated the robust optimization technology.

In this tutorial we restrict ourselves to linear optimization. We will treat the basics of robust linear optimization, and also show the huge value of robust optimization in (dynamic) multistage problems. Robust optimization has already shown its high practical value in many fields: logistics, engineering, finance, medicine, etc. In this tutorial we will discuss some of these applications.

Wednesday, 17:45-19:00

■ WF-01

Wednesday, 17:45-19:00 - O'Reilly Hall

Closing Session

Stream: Opening and Closing
Plenary session
Chair: *Seán McGarraghy*
Chair: *Luís Gouveia*

1 - Closing Session
Seán McGarraghy, Luís Gouveia

closing session

Streams

Algorithms on Graphs
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Track(s): 21

Analytic Hierarchy Process
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Track(s): 44

Analytics and Pricing
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Track(s): 34

Applications of Dynamical Models
Alberto Pinto
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Track(s): 48

Automated Warehouse System
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Track(s): 20

Behavioural OR
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Track(s): 47

Big Data in Complex Systems
Giuseppe Turchetti
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Track(s): 29

Blockchain and Cryptocurrencies: Economic and Financial Challenges
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Track(s): 28

Business Analytics
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Richard Weber
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Track(s): 20

Combinatorial Optimization I
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Track(s): 12

Combinatorial Optimization II
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Track(s): 16

Commodities and Financial Modelling
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Track(s): 27

Continuous and Black Box Optimization
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Track(s): 47

Continuous Optimization (contributed)
Track(s): 13

Control Theory and System Dynamics (contributed)
Patrizia Daniele
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Track(s): 49

Copositive and Conic Optimization
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Track(s): 10

Cutting and Packing
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A. Miguel Gomes
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Track(s): 25

Data Envelopment Analysis and Performance Measurement

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Track(s): 9

Data Mining and Statistics

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Track(s): 18

Data Science Meets Optimization

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Track(s): 30

Decision Analysis

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Track(s): 5

Decision Making Modeling and Risk Assessment in the Financial Sector

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Track(s): 28

Decision Making under Imprecise and Vague Information

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Track(s): 46

Decision Support Systems

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Track(s): 7

Demand and Supply Management in Retail and Consumer Goods

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Track(s): 23

Derivative-free Optimization

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Track(s): 10

Discrete and Global Optimization

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Track(s): 13

Dynamical Models in Sustainable Development

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Track(s): 49

Dynamical Systems and Mathematical Modelling in OR

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Track(s): 27 51

Dynamics and Games

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Track(s): 33

Emerging Applications in Portfolio Selection and Management Science

Norbert Trautmann
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Track(s): 19

Emerging Collaborative Economics and Management under Uncertainty

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Track(s): 19

Emerging Models for Transportation with Crowdsourcing

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Track(s): 29

Emerging Research on Education, Labor Markets and Transversal Competences

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Track(s): 20

Engineering Optimization

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Track(s): 46

Environmental Sustainability in Supply Chains

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Track(s): 20

EURO Doctoral Dissertation Award

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Track(s): 2

EURO Excellence in Practice Award

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Track(s): 2

EURO Journals

Track(s): 2

Financial Mathematics and OR

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Track(s): 27

Financial Modeling, Risk Management and Managerial Accounting (contributed)

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Track(s): 27

Forecasting and Time Series Prediction

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Track(s): 30

Frontiers of Dynamic Games and Management

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Track(s): 43

Fuzzy Optimization

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Track(s): 46

Game Theory and Mathematical Economics (contributed)

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Track(s): 35

Game Theory, Solutions and Structures

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Track(s): 35

Governance Analytics

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Track(s): 29

Graphs and Networks (contributed)

Track(s): 23

Green Logistics

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Track(s): 45

Healthcare Logistics

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Track(s): 35

IBM Research Applications

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Track(s): 21

Innovations in Supply Chain Network Models and Applications

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Track(s): 51

International Aspects of OR

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Track(s): 26

Inverse Optimization

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Track(s): 13

Knowledge and Knowledge Analytics

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Track(s): 19

Location Analysis and Optimization

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Track(s): 43

Lot Sizing, Lot Scheduling and Production Planning

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Track(s): 21

Maritime Transportation

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Track(s): 40

Mathematical Modelling

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Track(s): 33 34 48

Mathematical Models in Macro- and Microeconomics

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Track(s): 37

Mathematical Programming

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Track(s): 15

Metaheuristics

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Track(s): 29

Mixed Integer Programming

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Track(s): 14

Mixed-Integer Nonlinear Programming

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Track(s): 11

Modelling & Analytics for Energy Economics I

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Track(s): 6

Modelling & Analytics for Energy Economics II

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Track(s): 8

Moments in History of OR

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Track(s): 26 39

Multiobjective Continuous Optimization

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Track(s): 15

Multiple Classifier Systems and Their Applications

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Track(s): 18

Multiple Criteria Decision Aid

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Track(s): 38

Multiple Criteria Decision Making and Optimization (contributed)

Track(s): 34

Network Analytics and Optimization

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Track(s): 27

New Challenges in Investment Strategies, Risk and Financial Modelling

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Track(s): 23

Non-Standard Optimization and Decision-Making Methods

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Track(s): 44

Nonlinear Programming. Theory and Methods

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Track(s): 11 13

Numerical and Optimization Techniques Meet with OR

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Track(s): 20

Opening and Closing

Track(s): 1

Operational Research in Financial and Management Accounting

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Track(s): 28

Operations/Marketing Interface

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Track(s): 50

Optimal Control Theory and Applications

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Track(s): 51

OR and Ethics

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Track(s): 26

OR and the Arts, Creativity

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Track(s): 29

OR Applications in Industry

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Track(s): 48

OR Education

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Track(s): 4

OR for Development and Developing Countries

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Track(s): 5

OR for Sustainable Development

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Track(s): 5

OR in Agriculture and Forestry

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Track(s): 7

OR in Computational Biology, Bioinformatics and Medicine

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Track(s): 32

OR in Humanitarian Applications

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OR in Industry and Software for OR (contributed)

Track(s): 46

OR in Life Sciences

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Track(s): 32

OR in Neuroscience

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Track(s): 30

OR in Quality Management

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Track(s): 18

OR in Sports

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OR in the Physical Internet

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OR in Water and Hydro Energy Management

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Track(s): 5

ORAHS: OR in Health and Healthcare

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Track(s): 31

Plenaries

Track(s): 1

Practice of OR (Making an Impact)

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Track(s): 3

Production Planning and Control for Complex Manufacturing Systems

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Track(s): 22

Production, Service and Supply Chain Management (contributed)

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Track(s): 25

Project Management and Scheduling

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Track(s): 39

Public Transportation I

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Track(s): 41

Public Transportation II

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Track(s): 34

Rejected, cancelled and removed papers

Track(s): 1

Revenue Management (contributed)

Track(s): 33

Revenue Management in Production and Logistics

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ROADEF/EURO challenge

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Track(s): 2

Robust Optimization

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Track(s): 10

Scheduling with Resource Constraints

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Track(s): 37

Service Operations Management

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Track(s): 26

Soft OR, Problem Structuring Methods

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Track(s): 50

Software for Optimization

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Track(s): 49

Special Session 1

Track(s): 2

Stochastic and Robust Optimization

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Track(s): 8

Stochastic Modeling and Simulation in Engineering, Management and Science

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Track(s): 7

Stochastic Models and Queueing

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Track(s): 17

Supply Chain Management

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Track(s): 24

Sustainable Supply Chains

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Track(s): 5 22

Technical and Financial Aspects of Energy Problems

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Track(s): 17

Telecommunications and Network Optimization

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Track(s): 27

Timetabling

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Track(s): 39

Transportation

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Track(s): 42

Transportation and Logistics

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Track(s): 45

Tutorials

Track(s): 1

Variational analysis, games and intertwined optimization problems

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Track(s): 46

Vector and Set-Valued Optimization

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Track(s): 11

Vehicle Routing and Logistics Optimization I

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Vehicle Routing and Logistics Optimization II

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Track(s): 40

Women in OR

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Track(s): 1 2

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