Wednesday, 9:00-10:30

■ WA-03

Wednesday, 9:00-10:30 - POT/081/H

Opening Session and Plenary Presentation by the Winner of the GOR Science Award 2019

Stream: Plenary Presentations
Invited session
Chair: *Anita Schöbel*

1 - Plenary Presentation of the GOR Science Award Winner 2019
Or 2019

The winner of the GOR Science Award Winner 2019 will be announced during this session. After a short laudatio the winner will present his plenary talk.

Wednesday, 11:00-12:40

■ WB-02

Wednesday, 11:00-12:40 - POT/051/H

Collaborative Transportation

Stream: Logistics and Freight Transportation
Invited session
Chair: *Margaretha Gansterer*

1 - Dispatching of Multiple Load Automated Guided Vehicles based on Adaptive Large Neighborhood search
Patrick Boden, Hannes Hahne, Sebastian Rank, Thorsten Schmidt

This article is dedicated to the aspect of dispatching within the control process of Multiple Load Automated Guided Vehicles (MLAGV). In contrast to more common single load AGV, MLAGV are able to transport more than one load. This is accompanied with a significant increase of possibilities to assign transportation jobs to the vehicles. Against the background of high transportation system performance, this results in the challenge of efficiently assigning/dispatching pending load transports to available transport resources. In general, dispatching is considered as a challenging algorithmic problem (see Sinriech 2002).

The common way to solve the outlined problem is to select the next transportation job for the (ML)AGV by predefined dispatching rules. This, for example, can be the selection of the nearest location for load pick-up or drop off (see Co 1991). These static rules typically only consider the next activity to be executed. This, on the one hand, leads to transparent dispatching decisions and a short solution generation/computational time. On the other hand, results from literature indicate that high performance reserves are still remaining by using these simple approaches (see Sinriech 2002). In contrast to this we modeled the problem as Dial a Ride Problem (DARP, see Cordeau 2003) and solved a bunch of instances by the Branch and Cut algorithm. Clearly, this approach led to good solutions but is only applicable for small problem sizes due to extensive computational times. Since the dispatching of Multiple Load Automated Guided Vehicles is an online decision problem, an approach which is able to solve larger problem sizes within seconds must be found and applied.

So, in order to be able to dispatch an MLAGV fleet, a heuristic solution was identified and implemented. The heuristic is based on the Adaptive Large Neighborhood Search (ALNS) presented by Ropke (2006). Since this heuristic was originally developed for the Pickup and Delivery Problem with Time Windows, further constraints were considered to generate feasible solutions also for the DARP context.

We demonstrate that this heuristic approach solves all the instances former created for Branch and Cut algorithm with only small/acceptable loss of optimality but in significantly shorter time. The performance was investigated using static test instances related to a real MLAGV application in the semiconductor industry.

References Co (1991), A review of research on AGVS vehicle management. Cordeau (2003), A Branch-and-Cut Algorithm for the Dial-a-Ride Problem. Ropke (2006), An Adaptive Large Neighborhood Search Heuristic for the Pickup and Delivery Problem with Time Windows. Sinriech (2002), A dynamic scheduling algorithm for a multiple-load multiple-carrier system.

2 - Combinatorial Exchanges with Financially Constrained Buyers for Airport Time Slots
Richard Littmann, Martin Bichler, Stefan Waldherr

This talk is motivated by the exchange of airport timeslots granting rights for landing or take-off at crowded airports. Buyers are interested in bundles of slots and need to financially compensate the previous owner of a timeslot. In practice buyers are often financially constrained. We aim for an allocation and prices that maximize the gains from trade and are stable, i.e. no subset of the participants can deviate to their mutual benefit.

Bichler and Waldherr (2017) showed that finding stable prices in combinatorial exchanges with financially constrained buyers is Sigma-2-p

hard. We use bi-level mixed-integer programs to model these markets and develop algorithms to solve these problems. We then compare the outcome to that of a market where buyers can only reveal budget-capped valuations.

We report experimental results on the benefits of budget-constraints regarding social welfare and stability compared, and the instance sizes that we can expect to solve in practice.

3 - Decision support for sustainable regional food distribution

Christina Scharpenberg, Jutta Geldermann

An increasing demand for regional products can be observed in Germany. Consumers associate inter alia freshness, good quality and environmental friendliness with regional products. Two main advantages of purchasing food regional are freshness due to short travelling distances and strengthening the local economy. To keep transport distances as short as possible and to offer a broad variety of local products, supermarkets cooperate with small, regional producers. So far, this concept involves an increasing organizational and logistical effort due to a lack of standardization and due to special requirements of regional producers. This tends to higher costs of the logistics processes especially at a 'last mile' and a 'first mile'. Therefore, we investigated different vehicle routing strategies for the regional food distribution regarding their transport cost structure and transport emissions. Special attention is given to a fair cost distribution between the business partners. Our goal is to minimize costs and emissions caused by the transport through product bundling of multiple regional producers to find a more sustainable solution for the regional transport problem.

■ WB-03

Wednesday, 11:00-12:40 - POT/081/H

Revenue Management and Pricing

Stream: Revenue Management and Pricing
Invited session
Chair: *Robert Klein*

1 - Booking Limit based Revenue Management Approaches for Make-to-Order Production

Nina Lohnert, Kathrin Fischer

Due to the customization of products, variant diversity in production has been increasing enormously in recent years. This forces companies to redesign their production strategies, and more and more companies apply the make-to-order principle where production only starts after an order has arrived and also has been accepted. Due to capacity restrictions, however, not every order can be accepted and hence, acceptance decisions have to be made. Since the products have a high degree of individualization, demand and the customers themselves are strongly heterogeneous. Additionally, demand is usually stochastic, i.e. it is fluctuating over the time and difficult to predict. Thus, making optimal acceptance decisions is not straightforward. While in practice, mostly simple rules like first-come-first-served are applied for making these decisions, also revenue management techniques can be applied. In the literature some approaches for revenue management in make-to-order production have already been presented. However, most of them set their focus on the iron and steel industry and moreover, usually bid prices are used to make the order acceptance decisions. In contrast, in this talk booking limit based revenue management strategies for the order acceptance and the subsequent scheduling will be presented. Therefore, two mixed-integer linear programming models, one for the calculation of booking limits and one for the scheduling of the orders, are combined here to determine the optimal production schedule. The objectives to be pursued by a manufacturing company are usually two-fold: On the one hand, it will strive for (short-term) profit maximization. On the other hand, also the goal of providing good service in particular to valuable (i.e. regularly returning) customers is crucial in make-to-order production with respect to long-term success. These objectives are usually conflicting since valuable customers often get price discounts to tie them more closely to the company and its products. Hence, in this approach the service level aspect is taken into account by defining different aspired service levels for the different customer groups. Moreover, different booking limit nesting strategies are developed which lead to different results with respect to the conflicting objectives. The performance of the nesting strategies is tested on realistic data settings and it is compared to the performance of the first-come-first-served policy. It can be shown that overall the newly developed reverse nested booking limit approach leads to the best results. Based on these results, some implications for future research in the field of revenue management for make-to-order production are derived.

2 - Simulation-Based Approach for Upselling in the Airline Industry

Davina Hartmann, Jochen Gönsch, Sebastian Koch, Robert Klein, Claudius Steinhardt

Consider a well-known situation in air traffic: after purchasing a certain fare, an upgrade is offered to you for a specific amount of money, e.g. bigger legroom for 8 EUR . This is a so-called upsell offer. Airlines try to capitalize on the willingness to pay of the travelers. Both parties benefit: the airline might increase its revenue and the customer might receive a more personal offer, in the above-mentioned case additional comfort during her/his flight. The difficulty of this problem consists in not knowing the exact willingness to pay and in the calculation of the conditional purchase probabilities of the customers who already bought a ticket. Furthermore, after the initial ticket purchase, the airline has more information about these particular customers compared to random ones.

We differentiate two intervals of time: the booking horizon and the upsell horizon. First, during the booking horizon, random customers arrive and choose among the products offered the one that maximizes their utility. Thus, at the end of the booking horizon, there is a certain state of remaining capacity and tickets sold. If free seats of the higher-quality classes are left, the company can offer upsells, i.e. upgrades for which the customer pays a certain amount of money. The upsell horizon ends when either all high-quality seats are occupied or the airplane takes off. When doors close, the value of unsold seats drops to zero. We focus on the problem the company faces during the upsell horizon. After the booking horizon and before the upsell horizon the company has to decide on prices of the upsells. To do so, we suggest a simulation-based optimization model. We evaluate it with different test instances assuming that customer choice behavior in the booking horizon follows a multinomial-logit model.

3 - PAUL: Insourcing the Passenger Demand Forecasting System for Revenue Management at DB Fernverkehr - Lessons Learned from the First Year

Valentin Wagner, Stephan Dlugosz, Sang-Hyeun Park, Philipp Bartke

Railway Revenue Management offers great opportunities to increase revenues in practice and therefore is a common method in passenger rail business. One essential component of a Railway Revenue Management system is an accurate forecast of future demand. The Revenue Management System at Deutsche Bahn Fernverkehr (DB), a leading provider for long-distance passenger transportation in Germany with over 140 million passengers each year, was based on a third-party system designed for airline carriers. Based on the fundamental importance of the demand forecast, DB decided in 2017 to develop its own forecast environment PAUL (Prognose AUsLastung) to replace the legacy forecasting system utilized until then. Finding the most appropriate prediction model is a non-trivial task, especially for open systems like the German long-distance train network. Roughly speaking, there are three major ticket types having approximately equal market shares at DB: Standard Fare ("Flexpreis"), economy fare ("Sparpreis") and flat rates (e.g. "Bahncard 100", "Streckenzeitkarte"). They strongly differ in travelling conditions leading to very heterogeneous information they provide to any prediction model. Only the economy fare tickets are bound to certain trains and thus comparable to tickets common in airline business. Consequently, about two-thirds of all demand is not bound to specific trains so that little is known from ticket sales alone and additional sources of information are required. In our talk, we will present the conceptual and technical setup of PAUL which enabled us to reach our objectives: • Improved prediction quality compared to the previous forecasting environment quantified by MAPE. MAPE is defined as the mean absolute percentage error • Improved robustness compared to the precursor system against variations of the train travel path caused by timetable changes, additional trains, construction sites, . . . • Increased traceability and interpretability of the forecasting results • Ease to integrate additional data sources • Shorter innovation cycles By implementing the formulated objectives, we developed a forecasting platform that provides data integration and preparation as well as enabling our data scientists to quickly iterate on multiple machine learning models. The best-performing candidate models are combined into an ensemble forecast for the final prediction. Furthermore, we will look back at the first year using PAUL as a productive forecast environment, demonstrating that our goals are accomplished.

We address both the technical challenges we faced during the operationalization of PAUL as well as the ongoing improvements within the revenue management department.

4 - Capacitated price bundling for markets with discrete customer segments and stochastic willingness to pay - a basic decision model

Jacqueline Wand, Ralf Gössinger

Price bundling is an approach for determining a total price for a set of different products, which are offered as one unit. In the individual product case, a customer buys a product when his willingness to pay (wtp) is not below the price and earns a surplus in the amount of the difference between wtp and price. In the bundle case, the buying decision is taken anal-ogously, but with respect to bundle price and bundle wtp. Since the bundle wtp is an aggre-gation of single product wtps, within a bundle, products with positive surplus 'subsidize' products that would not have been bought solely. Thus, the sales volume and the profit can be increased due to price bundling when the wtps for different products are negatively cor-related. In general, optimization models for bundle prices are characterized by capturing ex-plicitly the behavior of both, vendor and customer. Up until now, for price bundling with discrete customer segments optimization models are used, which assume unlimited vendor ca-pacity and deterministic wtps for each customer segment. In the intended paper both as-sumptions will be cancelled. To do so, ideas of two research streams will be combined, which are not focused on discrete customer segments: (1) Sporadically, the model is generalized to the more realistic case of limited capacity. Thereby, the buying decision is captured on the level of individual customers whose behavior is binary (purchase, non-purchase). (2) To consider customers' diversity, the analysis is extended to the issue of stochastic wtp based on uniform or unimodal distributions. Since one customer segment consists of numerous individual customers, complementary to the first research stream we consider that buying behavior unfolds in quantities in a range depending on segment size. Furthermore, we pursue the second research stream in such a way that the wtp of each segment is represented with a separate distribution. In particular, this is relevant when the buying behavior within one segment is affected by additional incen-tives focusing on the risk perceived by the customer. Both aspects require a more differenti-ated consideration of customer behavior in the decision model. The suggested approach in-corporates both aspects into a MINLP model that can be solved by means of a standard solv-er (e.g. BARON). Based on a full-factorial numerical study the model behavior will be investi-gated in two respects: In order to identify economic implications of proposed generaliza-tions, the solutions to problem instances are compared with those to the cases with unlim-ited capacity and/or deterministic wtp. Furthermore, solution quality and solution time are analyzed in dependence on problem size, in order to conclude on the model applicability.

■ WB-04

Wednesday, 11:00-12:40 - POT/106/U

Software Applications and Modelling Systems I

Stream: Software Applications and Modelling Systems
Invited session
Chair: *Viktoria Hauder*

1 - Model deployment in GAMS

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.

2 - Mosel 5: New modelling and application design features for optimization projects

Susanne Heipcke, Yves Colombani

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 a number of implementation variants for the classical travelling salesman problem (TSP) using different MIP-based solution algorithms; this example shows the use of Mosel in the context of parallel or distributed computing, how to interact with a MIP solver, and various possibilities for the graphical visualisation of results. 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

3 - LocalSolver 8.5: integrating 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 in early 2019. The main novelty in LocalSolver 8.5 is its ability to compute lower bounds and in some cases to prove the optimality of the solutions found. This lower bound is obtained by a reformulation of the initial model, then solved with enumerative techniques combined with convex relaxations. In addition, this new version comes with an important performance improvement for set-based models, introduced in a previous version. LocalSolver 8.5 finds better solutions for such models, especially for routing problems (TSP, CVRP, Pickup and Delivery) as well as bin packing problems. As example, the average gap on the CVRPLIB instances goes from 5% in LocalSolver 8.0 to 1.6% in this new version. For unordered set models, as for bin packing problems, some lower bounds are also computed based on linearization and MIP-like resolution techniques. This new version is an important step toward the integration of mathematical programming techniques inside LocalSolver. LocalSolver 9.0 will continue in this direction by further exploiting linear and convex relaxations for combinatorial optimization and by leveraging interior point algorithms for continuous optimization.

4 - 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 flexible REST API, which accepts data using the industry-standard JSON format, 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 from various data sources such as spreadsheets and SQL/NoSQL databases directly 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.

■ WB-05

Wednesday, 11:00-12:40 - POT/112/H

Ridesharing, carpooling, mobility on demand

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Frank Meisel*

1 - A heuristic solution approach for the optimization of dynamic ridesharing systems

Nicolas Rückert, Daniel Sturm, Kathrin Fischer

The concept of dynamic ride sharing combines two important aspects of mobility: individualisation and sustainability. Ridesharing means that several people share a vehicle on their entire journey or for a part of it. Consequently, fewer vehicles are required to transport the same number of people. This new form of mobility is expected to have a huge impact on the mobility behaviour worldwide, as also recent activities of OEMs (like Volkswagen), Internet companies and Startups indicate. However, the key to a successful ridesharing service is a good coordination, and an efficient allocation and routing of vehicles and customers. This can be performed by suitable OR methods. On the basis of a literature search, case studies from practice and expert interviews, the relevant decisions which are required for the introduction of a dynamic ridesharing system regarding business model and operating area are identified, in addition to certain prerequisites such as the legal framework. This results in aspects which have to be taken into account in the development of quantitative solution approaches, such as vehicle capacity, maximum detour times, fastest possible routing and the assignment of new customers to vehicles already in operation. The above-mentioned conditions are transformed into a mathematical model for the operative optimization of ride sharing systems, improving existing models from the literature. Moreover, a new heuristic solution method for the optimization of a dynamic ridesharing system is developed and compared with the exact solution derived by a MIP solver based on the above-mentioned model.

The application example on which both approaches are tested consists of up to 60 customers in the urban area of Hamburg who request different rides and can be transported by a fleet of 10 vehicles. It is found that for this realistic application case the heuristic solution method is superior to the exact solution method, especially with respect to the required solution time. This is possibly due to the individual adaptation of the selected meta-heuristic to this particular dynamic ridepooling problem.

2 - A new framework for a vehicle sharing system

Selin Ataç, Nikola Obrenovic, Michel Bierlaire

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, determining pricing strategies, and demand forecasting. If these are not addressed properly, the system experiences a significant loss of customers and therefore revenue. Through the review of available literature, we have identified a lack of a unified approach of modeling all VSS aspects, with respect to different planning horizons, and a holistic solution approach to the related problems. Consequently, the goal of our work is to create a framework for VSS management that will encompass all decision-making tasks of the system and provide the best possible solution to the problems related to them. In order to achieve this, we have to simultaneously take into account all aspects of the system, i.e., to consider the impact the solutions of different problems have on each other. The contribution of this paper is to provide a wider perspective on the design and operations of shared mobility systems. While the literature has focused mainly on specific problems such as the routing aspect, many other methodological challenges are associated with such systems. The proposed framework provides a methodological map and attempts to cover the most important challenges of these mobility systems. Our further goal is the apply the framework to a system of shared light electric vehicles (LEVs), and design framework components tailored to the unique characteristics of such vehicles. To the best of our knowledge, the specific problems arising in the LEV sharing systems have not yet been addressed in the literature, and this paper represents the first consideration of such a system.

3 - Complex mobility requests in rural dial-a-ride problems with autonomous, electric vehicles

Lennart Johnsen, Frank Meisel

In the conventional dial-a-ride problem, each mobility request specifies a single origin-destination trip in a given time window. In this work, we present a problem variant of the dial-a-ride problem that allows for complex transport requests, which are characterized by e.g., multiple transport inquiries, round trips with residence times, or pickup requests of groups scattered in different locations. The problem is especially relevant for rural areas where alternative transportation systems are lacking. For example, a patient visiting a physician will only use the system if the return journey is guaranteed by the system and if the residence time is appropriate. Reasonably sized instances of this model are solved using the CPLEX MIP solver. We evaluate the planning tool by computational experiments considering the characteristics of a rural area (e.g., demand pattern, geography, travel times) and different customer types that vary in their preferences for travel price, travel time, punctuality, and trip convenience.

■ WB-06

Wednesday, 11:00-12:40 - POT/151/H

OR and renewables

Stream: Energy and Environment
Invited session
Chair: *Dominik Möst*

1 - Transmission and generation adequacy of a low-carbon electricity supply in Germany

Jens Weibezahn, Mario Kendziorski

This paper compares different transmission development scenarios for a low-carbon electricity future, using the open-source detailed, node-sharp electricity sector model Joulia.jl, written in the Julia programming language.

We analyze patterns of transmission utilization under more centralized or decentralized renewable generation scenarios. The model and scenario building are applied to Germany, which is currently undergoing a rapid transformation of its electricity sector, away from fossil fuels and nuclear generation towards high shares of renewables.

Based on an extensive model scenario exercise, preliminary results confirm the intuition that more centralized generation patterns lead to higher transmission utilization, whereas the requirements are reduced when generation and consumption are brought closer together, that is, the decentralized scenario.

2 - Financing the expansion of RES - subsidies vs. markets

Carl-Philipp Anke, Dominik Möst

Within the framework of the Paris Climate Protection Agreement, the international community of states has committed itself to limit the average temperature increase to 2 'C. To accomplish this, greenhouse gas emissions must be reduced. In the electricity sector, the sector with the highest carbon emissions in the EU, decarbonization can be achieved in particular through the expansion of renewable energies. The expansion of renewable energy sources (RES) has made great progress so far, as the installed capacities almost doubling in the last decade in Europe. This was mainly driven by governmental subsidies, which provide investors with sufficient incentives. However, these subsidies represent an intervention in the market so they cannot be optimal in terms of system costs but were necessary to allow the market entry of RES. However, this raises the question: How RES should be financed in the future? On the one hand, the competitiveness of RES will increase due to further shrinking investment costs; on the other hand, the previously installed RES will reduce the electricity price due to the merit order effect, which, as is well known, enforces to the missing money problem. The contribution of this paper is twofold: • First, there will be an analysis of the further expansion of RES with regard to its financing. Thereby a finance system driven by government subsidies will be compared to market-based financing. Evaluation criteria are overall system costs and the achievement of climate targets. • Secondly, the missing money problem will be analyzed depending on the installed capacity of RES. Hereby a focus lies on technology mix (Wind - PV) that will be installed. The basis for the above-mentioned analysis is the European power market model ELTRAMOD, which is based on a cost minimization approach with a temporal resolution of 8760 hours including corresponding consumption curves and feed-in time series of renewable energies (wind onshore and offshore, photovoltaic and run-of-river power plants). It determines power plant investments and investment decisions as well as the power plant dispatch

in the European electricity market. In its basic spatial resolution, the model includes the EU-27 states as well as Switzerland, Norway and the Balkan countries, each with a detailed representation of regional energy supply structures. The trading activities between the individual market areas are limited by net transport capacities (NTC). Similar to trading on the day-ahead market, network bottlenecks within a market region are neglected ("copper plate"). The European Union Emissions Trading System (EU ETS) for CO2 is considered and can be modeled both endogenously and exogenously. First results of this work will be presented at the conference.

3 - Market Design for Wind Auctions: An Analysis of Alternative Auction Formats in Germany

Paul Sutterer, Martin Bichler, Veronika Grimm, Sandra Kretschmer

Since the update of the Erneuerbare Energien Gesetz (EEG) 2017 capacities and feed-in prices for wind-onshore energy plants are determined by national auctions. As a result, most of the energy plants were built in the windier north, further increasing the gap in energy production between the north and the south. The increasing issue of network shortage and instability asks for adjustments of the process. However, even the introduction of a so called Referenzertragsmodell (REM), which aims at monetary compensation for energy plants at less windy locations, could not resolve the issue. A recent report by Grimm et al. 2017 argues for a decentral energy production with proximity to actual demand. They state that such a system optimal allocation could spare a lot of money for several reasons such as less investment that is required for the extension of the energy grid. In this study, we present alternatives to the currently applied auction design. Those alternative designs allow to define regional demand constraints in order to implement a system optimal allocation. Especially, the National Package auction allows bidders to express potential synergy effects directly and can therefore mitigate some of the extra cost caused by forcing a specific allocation. Moreover, it leads to anonymous and (mostly) linear prices. We evaluate all auction designs for several settings and find the National Package auction to be a real alternative to the current auction design.

■ WB-07

Wednesday, 11:00-12:40 - POT/251/H

Electric busses

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Michal Kohani*

1 - Integrating Battery Electric Buses in Urban Bus Networks

Nicolas Dirks, Maximilian Schiffer, Grit Walther

Cities around the world are struggling with harmful urban air quality, mainly caused by transportation related emissions. In public transportation, battery electric buses provide a promising alternative to internal combustion engine buses to fulfill urban air quality thresholds. Hence, many bus network operators currently pursue an optimal transformation process integrating battery electric busses into their fleet. Besides integrating buses, operators have to install sufficient recharging infrastructure at the right locations to ensure a fleet's operational feasibility. Designing such a transformation process demands a modeling approach that captures its inherent complexity.

Against this background, we introduce an integrated modeling approach for a cost-optimal long-term, multi-period transformation process to integrate battery electric buses into urban bus networks. We minimize total cost of ownership based on a comprehensive mixed-integer programming model. Herein, we account for costs and revenues due to dynamic bus purchases and sales, battery replacement, battery price reduction, recharging infrastructure development as well as bus network operations. We assess reductions of NOx emissions a-posteriori. Our model links relevant strategic decisions on bus fleet and recharging infrastructure with operational decisions constrained by given vehicle schedules.

We apply our model to a case study of a real-world bus network. A comprehensive analysis of experimental results based on real data allows us to validate our model and to identify promising managerial insights. Besides presenting a cost-optimal transformation process, we analyze feasibility of emission thresholds and electrification targets, technical characteristics, operational decisions as well as the impact of battery cost reduction on total costs. Results show that a comprehensive integration of battery electric buses is feasible regarding fleet operation and bus schedules. Moreover, battery electric buses are even able to operate a majority of trips of the bus network more cost-efficiently due to operational cost savings. In addition, we show that for our case study, high-power recharging facilities and batteries are superior to low-power devices.

2 - Data reduction algorithm for the electric bus scheduling problem

Maros Janovec, Michal Kohani

The implementation of the electric vehicles in the public transport system may decrease the emissions and reduce the operational costs. We focus our research on problems related to the transformation of the conventional bus fleet into the fleet of electric buses. During the transformation different problems must be solved. One of them is the scheduling of the electric buses. In this problem we need to assign available electric buses to the service trips, which means we create a schedule of service trips for each used electric bus. The classic vehicle scheduling problem is quite well researched and good methods of solving the problem were proposed. However, the electric bus scheduling has more limitations than the scheduling of conventional busses due to the nature of electric buses. The most limiting factor is the limited driving range of electric bus, which is usually between 100 and 300 km and it is not enough to drive the whole day workload. Next limiting factor is the time needed to recharge the battery, which is much longer than the time needed to refuel the conventional bus. Therefore, the electric bus must charge more times during the day and this charging takes more time. With the charging the position of and number of needed chargers comes into the question. In our case we assume that the locations and numbers of chargers are known. In our previous research we proposed a linear mathematical model of the electric bus scheduling problem. During the experiments with the model we found the limit of the problem size that can be solved exactly with the standard IP solver. The highest impact on the computation time had the number of service trips. There are few possibilities, if we want to solve the problems with high number of service trips. First alternative Is change of mathematical model or the solution method. The second possibility is to reduce the number of service trips by combining several trips into one service trips, that would not change the optimal solution. In this paper we propose an algorithm to reduce the number of service trips. The reduction is based on natural grouping of the trips, for example, the first trip goes to the peripheral district where is no charger and the second trip is following the first trip in few minutes and goes in the opposite direction from the fist one, therefore the combined trip would start in the center of the city, then go to the peripheral district and back. Proposed algorithm is applied to the service trips from the city of Žilina provided by the public transport system provider DPMŽ. Then the solution of the scheduling problem with reduced number of service trips is gained by the standard IP solver Xpress IVE and compared to the solution of the scheduling problem with no reduction of number service trips.

3 - Extension of location of charging stations model for electric buses with nonlinear charging functions

Dobroslav Grygar, Michal Kohani

Design of the charging infrastructure for battery electric buses in public transport has been studied in several works and various models have been developed. In most of them, assumptions and simplicity of charging events are presented. Mainly absence of charging events or simplicity of modeling battery state of charge with simple linear function appears in these approaches. In this paper, we aim to extend existing mathematical model with properly modeled state of charge with nonlinear charging functions as this model charging of the battery more accurate. We focus on linear approximation of nonlinear charging functions and we extend our base model with proposed approximations in order to examine if change of the model can produce different solutions. Our base model solves problem of locating charging stations on terminal stops and depots of the public transport system. We use various datasets based on real data from operating of public transport system to test our extended model.

4 - Various strategies for the electric bus scheduling

Michal Kohani, Maros Janovec

Our research is focused on the electric bus scheduling problem in the system with plug-in charging in the depot or in selected bus stops equipped with the fast-charging possibilities. In comparison with the scheduling problem of conventional diesel buses, we need to take into account more limiting factors and constraints. First limiting factor is

the limited driving range of electric buses. With current technologies and capacities of batteries, the driving range is usually between 100 and 300 km. In most of the city public systems this driving range is lower than the range needed to drive the whole day workload. Another limiting factor is the charging time, usually most of electric buses need to be charged during the day. In our problem the location of charging stations, number of chargers and charging speed is given. Our goal is to create feasible and optimal schedule of all electric buses with respecting all necessary limiting factors. We proposed a linear mathematical model of the electric bus scheduling problem. In our previous research we used the number of buses as the optimization criterion. Since there can be more different optimization criteria, in this contribution we study various criteria based on the minimizing of the empty service trips or cost related to the bus operation in the area. Proposed mathematical model with various criteria is tested on to the data of the city public transportation in the city of Zilina provided by the public transport system operator DPMZ. Numerical experiments are performed on the standard IP solver Xpress and the influence of various criteria on the solution quality and computation time is studied.

■ WB-08

Wednesday, 11:00-12:40 - POT/351/H

Last-Mile Delivery 1

Stream: Logistics and Freight Transportation
Invited session
Chair: *Stefan Irnich*

1 - Freight pickup and delivery with time windows, heterogeneous fleet and alternative delivery points

Jérémy Decerle, Francesco Corman

Recently, the rapid and constant growth of online sales has raised new challenges for freight delivery. While the volume of goods to deliver increases, last-mile delivery should improve to meet customers' expectations such as same-day delivery. Nowadays, customers expect to receive their order urgently and at a precise time with perfect reliability. However, the traditional home delivery is showing its limits. Last-mile secured delivery to home requires the presence of the customer at his home, mostly during office hours when there is most likely no one at home. As a result, delivery is frequently rescheduled on a later date. To deal with that, several alternatives have recently appeared to give customer greater choice on where to pick-up goods. Among them, click-and-collect option has risen through the development of locker points where goods can be delivered, and later collected by the customer at any time. Another alternative is the store pick-up of goods by customers. While locker points give more flexibility for the customer to pick its goods, it is also five times cheaper than home delivery for the seller.

In order to solve this problem, we study a novel variant of the pickup and delivery problem. The aim is to determine the optimal way to construct a set of routes in order to satisfy transportation requests. Each transportation request consists of picking up goods from a predetermined location and dropping them to one of the predetermined delivery location. The novelty of this approach lies in its flexibility, which offers several options for the delivery location, including the customer's home, parcel lockers and stores, previously chosen by each customer. Indeed, an upstream assignment of orders to potential delivery locations is performed prior to the resolution according to the wishes of the customers. Additionally, pickup and deliveries of goods are restricted by some capacity and time window constraints. Finally, different types of vehicle of different capacity, speed and characteristics, possibly also including vehicles running on fixed schedules like public transport services, are considered for the planning. Hence, it is also important to determine which vehicle best fits each transportation request.

In this regard, we propose a mixed-integer programming model of the pickup and delivery problem with time windows, heterogeneous fleet and alternative delivery points. In order to validate the proposed model and estimate the potential gain in terms of traveling time, some experiments are performed on various instances representing different configurations using the commercial optimization solver Gurobi. The results highlights the decrease of traveling time by taking into account several alternative delivery points instead of the traditional home delivery. Indeed, goods of different customers can be delivered at a mutual location, and thence reduce trips for single-good delivery.

2 - Planning last-mile deliveries with mobile pick-up stations

Tino Henke, Saba Pakdel, Trong Dai Pham, Thi Kim Nhung Phan

Growing e-commerce, increasing urbanization, and environmental concerns have led to the introduction of several innovative last-mile delivery concepts in recent years with the intent of overcoming deficits of traditional attended home deliveries. Such concepts cover different pick-up concepts like (fixed) pick-up stations, distribution by alternatively-powered vehicles like cargo bikes, or deliveries by unmanned vehicles like drones. Another recently introduced concept is the usage of mobile pick-up stations. Similarly to the already well-established fixed pick-up stations, mobile pick-up stations contain several lockers in each of which a parcel can be stored for individual customer collection. In contrast, however, mobile pick-up stations are smaller and can be moved to a different position each day or even multiple times a day. Considering mobile-pick-up stations for last-mile deliveries gives rise to several interesting optimization problems which combine aspects of location planning and vehicle routing. In this presentation, one particular problem is studied, in which in addition to mobile pick-up stations, attended home deliveries are considered for customers living in sparsely populated areas. Consequently, for each customer to be served on a given day, it needs to be decided which delivery option to use. Further planning decisions in this problem include the determination of parking locations for mobile pick-up stations as well as vehicle routes for attended home deliveries. The objective is to minimize the total last-mile delivery costs. For solving this optimization problem, a sequential multi-stage heuristic has been developed, in which clustering of customers, delivery mode determination, location planning, and vehicle routing are performed on different stages. Extensive numerical experiments have been conducted to evaluate the performance of the proposed heuristic, and valuable managerial insights into the benefits of using mobile pick-up stations have been obtained.

3 - Simultaneous Planning for Disaster Road Clearance and Distribution of Relief Goods: A branch-and-bound based solution method and a computational study

Denis Olschok, Alf Kimms, Dirk Briskorn

During the last years the number of natural disasters such as hurricanes, earthquakes and tsunamis has grown. Furthermore, more and more people have been affected by disasters. Not only because of this an efficient planning of relief operations is of utmost importance. In the phase immediately after the occurrence of a disaster it is an urgent task to supply the disaster victims in the affected region with relief goods. The last mile delivery is mainly carried out by road vehicles. 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. Next to several mixed-integer programming models an exact solution method is developed and the results of a comprehensive computational study are discussed.

4 - Vehicle Routing Problem with Alternative Delivery Options

Katharina Olkis, Christian Tilk, Stefan Irnich

The presentation introduces the Vehicle Routing Problem with Alternative Delivery Options. The ongoing rise in e-commerce comes along with an increasing number of first-time delivery failures due to the absence of customers at the delivery location. Failed deliveries result in a number of issues such as rising customer dissatisfaction and higher delivery costs. In contrast to the classical vehicle routing problem with time windows, in which each customer request is represented by exactly one location and time window, alternative delivery options imply that at least some customer request can be fulfilled at more than one location. For example a customer could request a delivery to take place at home in the morning, at work in the afternoon and at a locker in the evening. Furthermore, the customer can to prioritize their options. A location can either represent a single request, e.g. a customer's home, or represent multiple requests, e.g. locker. The carrier must then decide for each request to which of the given alternative delivery options the shipment is sent such that the carrier's overall costs are minimized and a certain service level regarding the customer's preferences is achieved. Moreover, when delivery options share a common location, location capacities must be respected when assigning shipments.

To solve the problem, we present a branch-price-and-cut. The resulting pricing problem is a shortest-path problem with resource constraints that is solved with a bidirectional labeling algorithm on an auxiliary

network. We investigate two different modeling approaches for the auxiliary network, an optionbased network and a locationsbased network. In the optionbased network, each vertice represents a customer's option. In the location-based pricing network each multiple request location is represented by an entry and exit vertex. In between the entry and exit vertice, additional vertices represent the delivery options at that location. The resulting network contains less arcs but more vertices then the optionbased network. We present optimal solutions for instances with up to 60 requests.

■ WB-09

Wednesday, 11:00-12:40 - POT/361/H

Inventory Management

Stream: Production and Operations Management
Invited session
Chair: *Christian Larsen*

1 - Controlling inventories in omni-channel distribution systems with variable customer order sizes

Lina Johansson, Peter Berling, Johan Marklund

Omni-channel distribution systems brings new challenges for efficient inventory control. One such challenge concerns service differentiation across channels when upstream central warehouses satisfy both direct customer demand and replenishment orders from downstream retailers. In traditional one-warehouse-multiple-retailer (OWMR) inventory systems where the central warehouse only replenish downstream retailers, research has shown that it is optimal with a relatively low service level at the central warehouse. This is typically not a viable solution in an omni-channel system as all customers including those that order directly from the central warehouse expect a high service level. Motivated by collaboration with industry and real data characterized by highly variable customer order sizes and service level constraints, we consider this problem in the context of an OWMR model with direct customer demand at the central warehouse and (R,Q) policies at all inventory locations. Moreover, service differentiation at the warehouse is achieved by reserving some stock for the direct customer demand. We model this by introducing a base-stock controlled virtual retailer at the warehouse with a replenishment lead-time of zero if the warehouse has stock on hand. The base-stock level S is interpreted as a reservation level at the warehouse. Similar approaches have previously been successfully used for backorder cost models in the literature. In these models, an attractive feature is that methods for traditional OWMR systems can be applied directly to evaluate and optimize the system. In our settings with fillrate constraints and highly variable customer order sizes, this is no longer the case; direct application of such methods can lead to poor solutions. For this type of systems, we present computationally efficient approximation methods for determining the reorder levels at all stock points and the reservation level at the central warehouse. A numerical study, including real data from two different companies, illustrate that the proposed methods perform well, rendering near-optimal solutions close to target fill-rates and offering significant opportunities to reduce total inventory costs compared to existing methods.

2 - Estimation of the fill rate in a lost-sales (R,Q) system with non-observable demand transactions

Christian Larsen

We study an (R,Q) inventory system where the size of the replenishment order, Q, is predetermined and assuming unfilled demand is lost. We furthermore assume that it is not possible to get access to any detailed point of sales data. Known only are the inventory levels, just prior to the receipt of the incoming replenishment orders. Under these circumstances we investigate different procedures for estimating the fill rate for a given re-order point R. Thereafter we investigate the case where the possible information are only collected in a few cycles and an initial determination of the re-order point R is made in order to secure a fill rate target. As new information is collected, the re-order point is recalculated. We investigate whether such a procedure will make the re-order point converge to the re-order point that would have been computed, if knowing the underlying (compound Poisson) demand process.

3 - Optimally Solving 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 approach for optimally solving the problem is presented.

■ WB-10

Wednesday, 11:00-12:40 - ZEU/114/H

Airport Ground Operations

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Michael Schultz*

1 - Capacity planning for airport runway systems

Stefan Frank, Karl Nachtigall

Runway systems commonly represent a bottleneck at major international airports. In order to cope with the continuing growth of aircraft movements and thus increasing demand at these airports, capacity management is applied to determine and exploit the maximal throughput of an airport, while infrastructure expansions are usually not the method of choice due to their high investment costs. Therefore, we present a mixed-integer programming formulation. The objective in this model is to minimize the delay of aircraft movements for a given planning horizon while capacity restrictions need to be observed. We show how this general model can be extended to include additional restrictions, e.g., based on turnaround requirements, different aircraft classes, or individual separation times. The model is solved by a column generation approach where the subproblem is represented as a shortest path problem. Additionally, a lower bound based on Lagrangean relaxation and a primal rounding heuristic is used in our approach. We illustrate our methodology with an example and show results on academic and real-world problem instances.

2 - Optimizing winter maintenance service at airports

Henning Preis, Hartmut Fricke

Preserving the efficiency of an airport during winter operations and corresponding conditions requires proper configuration of the snow removal fleet and its smart operation by using optimal routing schemes to clean the airport's airside. In this paper, we present a two-stage approach for optimizing typical winter operations at large airports. In the first stage, we estimate the minimum fleet size to undertake maintenance operations in due time based on a vehicle capacity model. We consider various vehicle parameters, dedicated airport maps with allocated service areas and potential service level agreements between airport operator and airlines acting as customers. In the second stage, the optimal routing of the vehicles is determined under the objective of minimizing the cleaning time of pre-defined areas. We apply a specially adapted variant of Vehicle Routing Problem with problem-specific constraints such as vehicle synchronization for joint snow removal, restrictions resulting from the wind direction and, further more the preference of runways over taxiways. With the help of the developed methodology it is possible to verify potential investments into fleet resources, which might seem to be necessary to meet increasing service level requirements. The methodology is being demonstrated for Leipzig-Halle Airport (LEJ).

3 - A Microscopic Control Method for Aircraft Turnaround Operations Running in Parallel at Busy Hub-Airports

Jan Evler, Ehsan Asadi, Henning Preis, Hartmut Fricke

The proposed paper introduces an optimization model for the control of multiple and simultaneous aircraft turnaround operations at an exemplary Hub-airport. The scheduling approach integrates multidimensional network-interdependencies of aircraft-, crew- and passenger-routings as well as airport-specific resource constraints into a microscopic process model, which is supposed to support Airline Operations

Controllers in their decision for network-optimal recovery actions in case of schedule disruptions. The model comprises a wide range of potential process and network sequencing alterations, which are analysed for their individual and joint impact on the turnaround finalization time, called target off-block time (TOBT), of all parallel turnarounds. The underlying objective is to minimize network delay costs for an exemplary airline whilst adhering to operational constraints of the observed airport environment. The variety of control measures includes the acceleration of processes, either by assigning additional resource units or by eliminating certain sub-tasks from the standard procedure, the elimination of network links for passenger or crew connections, and the alteration of assigned resources, such as ground handling equipment, airport parking positions or de-icing slots. The optimization is considered a mixed-integer problem and is solved using standard solution methods in GUROBI in order to create a baseline case for the introduction of process uncertainties in further research steps.

4 - Coping with uncertainties in predicting the aircraft turnaround time holding at busy airports

Ehsan Asadi, *Jan Evler*, *Henning Preis*, *Hartmut Fricke*

Predicting the target time of an aircraft turnaround is of major importance for the tactical control of airport and airline network operations. Nevertheless, this turnaround time is subject to many random influences, such as passenger behaviour while boarding, resource availability, and short/notice maintenance activities. This paper proposes a mathematical optimization model for the aircraft turnaround problem while considering various uncertainties along the process. The proposed method is acting on a microscopic, thus detailed operational level. Dealing with uncertainties is implemented by two approaches. First, an analytical procedure based on convolution, which has not been considered in the literature so far but provides fast computational results, is proposed to estimate the turnaround finalization, called target of block time (TOBT). It takes all process-related stochastic influences into account and calculates the probability that a turnaround can be completed in a pre-set due time. To assess the performance of the convolution, the network is simulated by the given distribution functions of specified turnaround sub-processes with known results of the Monte Carlo simulation. Since aircraft turnaround operations reflect a scheduling problem, a chance constraint MIP programming model is applied as the second approach. This procedure implements stochastic process durations in order to determine the best alternative of variable process executions, so that the scheduled completion time given from the flight plan is very likely to met. The procedure focuses on a simplified, exemplary model of an Airbus A320 turnaround.

■ WB-11

Wednesday, 11:00-12:40 - ZEU/118/H

MILP Models in Project Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Norbert Trautmann*

1 - A High-Performance MILP Model for RACP

Lukas Barth, *Nicole Ludwig*, *Dorothea Wagner*

The Resource Acquirement Cost Problem is a flavor of the well-known Time-Constrained Project Scheduling Problem (TCPSP). In this problem, jobs that are associated with a usage of a set of resources must be scheduled with hard deadline and release time constraints. The objective is to minimize a linear combination of the maximum usage of each resource.

Popular optimization techniques for RACP instances include various meta heuristics, constraint programming, which has caught much attention lately, and mixed-integer linear programming (MILP), which still remains the probably most widely used technique. While there are plenty of MILP models adapted to various special cases of the RACP, many of these models use a small number of techniques at their core to provide the basic functionality, such as linking jobs' start times to resource usage over time. Perhaps most popular among these techniques are discrete-time models. Other common MILP modelling techniques are event-based models and flow-based models. For an overview, see [1], which introduces a number of models originally intended for the Resource-Constrained Project Scheduling problem. However, the presented models are straightforward to adapt to the TCPSP.

We present a - to our knowledge - novel technique, which we call an order-based model. Instead of having indicator variables for start times of jobs (as with discrete-time models), or decision variables indicating that a certain job starts at a certain event (as with event-based models), our technique uses decision variables denoting whether a certain job is started before or after each other job. The main difficulty for each MILP model solving TCPSP problems is to obtain the total demand of each resource at every point in time from the decision variables. To optimize for the RACP, we only need the peak demand of each resource. To obtain this peak demand from such an order-based formulation, the key insight is that the peak demand can only occur at the start of a job, thus we build constraints that use the order-indicating variables to construct the demand of each resource at the start of each job.

We evaluate this MILP model on a set of instances based on real-world data collected in a smart-grid context, where jobs are processes requiring a certain amount of electrical power during their execution, and power is the only resource. Our evaluation shows that in many cases, our new modelling technique allows for the optimization of larger problems than the traditional discrete-time or event-based models, which we also evaluate. Also, we gain the insight that for TCPSP problems, discrete-time formulations seem to outperform event-based models, which stands in contrast to the results presented in [1].

[1] O. Koné, C. Artigues, P. Lopez, and M. Mongeau, "Event-based MILP models for resource-constrained project scheduling problems," Computers & Operations Research, vol. 38, no. 1, pp. 3-13, Jan. 2011.

2 - A MIP-formulation for the resource renting problem

Max Reinke, *Jürgen Zimmermann*

Heavy machinery used in construction projects is usually rented by contractors. Taking this into account the resource renting problem (RRP) aims at minimizing the total renting costs for resources used in a project. The RRP was introduced by Nübel (2001) and extends the well-known resource availability problem, which only considers time-independent procurement costs, by also taking time-dependent renting costs into consideration. When procurement costs are significantly higher than renting costs for a resource unit, sometimes it may be beneficial to keep renting a resource even when it is not in use at the time, rather than paying the procurement costs again later. To solve the RRP one has to obtain a time feasible schedule regarding all activities and also determine an optimal renting policy incurring minimal renting costs, by deciding when to procure resources and when to release them. In our work on this subject, we developed for the first time a time index based MIP formulation for the problem at hand. In an effort to improve the performance of a standard MIP-solver like CPLEX, we proposed some additional constraints for the problem to decrease the number of possible solutions, by tightening the lower and upper bounds for the decision variables representing the resource demand. We used three different lower bounds to determine the minimum number of resources that had to be procured to complete the project in time. Within a performance analysis, we show the effect of the proposed bounds regarding the solution quality and time for our MIP formulation. An optimal solution of the RRP usually includes time intervals were rented resources are idle. Going back to the initial example, some construction machines can be used for a variety of different operations, usually not all of them are machine specific. Some tasks can be performed equally by different types of machines (resources). For example, to lift some heavy materials at a construction site, a mobile crane as well as an excavator with a chain are suitable choices of equipment. In an effort to utilize idle resources and therefore reduce the renting costs for a project, we extended the RRP by the option to substitute resource. To allow this type of resource exchange in our model we introduce substitutable resources, where the demand can be satisfied by providing a sufficient number of units of any suitable resource. We show this extension is a special case of the multi-mode case for the RRP. To test the proposed extension we modified our MIP model by adding substitute resources and compared the performance with a multi-mode RRP MIP formulation.

3 - A continuous-time formulation for the multi-site resource-constrained project scheduling problem

Norbert Trautmann, *Mario Gnägi*

The multi-site resource-constrained project scheduling problem can be described as follows. Given are a set of precedence-related activities of a project which require various renewable resources during execution. Moreover, there is a set of several sites at which the activities can be performed; some of the resources can be moved between the sites, while other resources are permanently assigned to one site. The transport of a resource between different sites requires a prescribed amount of time, which depends on the sites distance. The same amount of time is required when two precedence-related activities are performed at different sites, which corresponds to a transport of an intermediate

product. The problem is to determine a site and a start time for each activity such that the project duration is minimized, all precedence relationships are taken into account, for each resource the total requirement never exceeds its available capacity, and the transportation times between the sites are taken into account. We present a novel continuous-time mixed-integer linear programming formulation for this problem and report on computational results for a test set from the literature.

■ WB-12

Wednesday, 11:00-12:40 - ZEU/146/Z

Algorithmic Approaches for Scheduling and Ordering Problems

Stream: Discrete and Integer Optimization
Invited session
Chair: *Andreas Linß*

1 - Exact and Heuristic Approaches for the Weighted Linear Ordering Problem

Tobias Lechner, Jessica Hautz, Kerstin Maier, Peter Rescher

In this work, we introduce and analyze an extension of the Linear Ordering Problem (LOP). The LOP aims to find an arrangement of a given set of nodes with directed pairwise weights that can be interpreted as benefits, such that the total sum of benefits is maximized. Benefits are obtained if a certain node is located before another in the permutation. We propose the weighted Linear Ordering Problem (wLOP) that considers individual node weights in addition to pairwise weights. Therefore, the benefits for each pair of nodes are also dependent on the individual node weights of those nodes located between the node pair.

The wLOP is both of theoretical and practical interest. First, we show that the wLOP generalizes the well-known Single Row Facility Layout Problem by allowing asymmetric cost structures. Additionally, we argue that in several applications of the LOP the optimal ordering obtained by the wLOP is a worthwhile alternative to the optimal solution of the LOP. As an example, let us consider the scheduling of appointments. The pairwise node weights define the preference of arranging one appointment before another. Modeling this problem as a wLOP instead of a LOP allows us to further position time consuming appointments far away from each other.

We introduce two Integer Linear Programming formulations as well as a Variable Neighborhood Search for solving the wLOP. Finally, we provide a large benchmark library and demonstrate the efficiency of our exact and heuristic approaches on these instances in a computational study.

2 - Linear-time approximation algorithms for minimum subset sum and subset sum

Liliana Grigoriu

We present a family of approximation algorithms for minimum subset sum with a worst-case approximation ratio of 1+1/k and which run in linear time assuming that is constant. We also present a family of linear-time approximation algorithms for subset sum with worst-case approximation factors of 1 1/(k + 1) assuming that k is constant. The algorithms use approaches from and improve upon previous literature, where a linear-time 4/5 approximation algorithm for subset sum and a 5/4 linear-time approximation algorithm for minimum subset sum have been provided by Kellerer and by Grigoriu and Briskorn respectively. The maximum number of times a linear-time procedure could be called within the algorithms, which depends on k, is determined computationally for each of the two problems for sample values of k up to k = 80. For example, for k = 10, this number is 137 for subset sum and 171 for minimum subset sum, for k = 20 these numbers are 2712 and respectively 3085, and for k = 30 they are 28627 and respectively 31023. We also comment on how the algorithms can be parallelized. The simplicity of the algorithms allows for fast implementation.

3 - Optimal Student Sectioning at Niederrhein University of Applied Sciences

Steffen Goebbels, Timo Pfeiffer

Study courses with a largely fixed timetable require centralized planning of student groups (sections). Typically, group sizes for exercises and praticals are small, and different groups are taught at the same time. To avoid late or weekend sessions, exercises and practicals of the same or of different subjects can be scheduled concurrently, and the duration of lessons can vary. By means of an integer linear program, an optimal group division is carried out. To this end, groups have to be assigned to time slots and students have to be divided into groups such that they do not have conflicting appointments. The optimization goal is to create homogeneous group sizes.

4 - A branch-and-price algorithm for job shop scheduling with flexible energy prices and time windows

Andreas Linß, Andreas Bley

The increasing variation of the energy prices has a strong effect on production industries and leads to new optimization goals in the area of machine scheduling. In this presentation, we consider the job shop scheduling problem with flexible energy prices and time windows. In this problem, we are given a set of different machines and a set of jobs which need to be processed within their respective time windows. Each job consists of several tasks that need to be processed on specific machines in a given order. In addition to its processing time, each task also requires additional setup-time immediately prior processing on its respective machine. For the machines, we consider several operational states with state dependent energy consumption. Machines can be either offline, in ramp-up, in setup, in processing, in standby, or in ramp-down state. Technical constraints restrict the duration and the switching between these states. Finally, we are given energy prizes for each period of the discretized time horizon. Our task is to determine a schedule of the tasks and machine states that minimizes the total cost energy consumption, respecting the time windows, the task precedences constraints, and the (state dependent) machine resources. First, we present a natural IP formulation based on time-index scheduling and machine state variables. Due to the huge number of variables and the symmetries in the formulation, however, the resulting models suffer from poor LP relaxation and are not solvable within a reasonable amount of time. In order to cope with these problems, we then propose a reformulation of the problem, which uses so-called break-variables to explicitly describe all possible ramp-down - offline - ramp-up sequences between the active machine states (and similar sequences at the beginning and the end of the planning horizon), and a column generation approach to generate these variables iteratively. We discuss the pricing problem, some bounding techniques, the branching scheme, and the heuristics that are used in our implementation of a branch-and-price algorithm for the problem. Finally, we report on our computational experiments. Our column generation approach led to an acceleration of the solution process and improved the best known lower bounds for some benchmark instances, and we are looking confidently to more improvements of this model.

■ WB-13

Wednesday, 11:00-12:40 - ZEU/147/Z

Operational Planning and Stochastic Simulation I

Stream: Simulation and Statistical Modelling
Invited session
Chair: *Maximilian Moll*

1 - An error flexible multiple testing procedure for small operational management related hypotheses families

Christina Bartenschlager, Jens Brunner

For small operational management related hypotheses families, as in model testing, multiple stepwise tests dominate multiple single step tests. We propose and suggest a modification to the single step error flexible (SiMaFlex) procedure introduced by Bartenschlager and Brunner (2018b) for such hypotheses families. We call the new method stepwise based margin based error flexible (SteMaFlex) test. The basic idea of our SteMaFlex procedure is to weigh the conventional tests and stepwise Bonferroni modifications provided by Holm (1979) and Hochberg (1988). Applications of the new method to both real life scenarios and simulated business data show that the SteMaFlex procedure dominates Hochberg's, Holm's and SiMaFlex methods in terms of FWER conditions. For an FDR error definition, the method is advantageous in terms of the type I error criterion. In addition, the method is robust to imprecise estimation of the proportion of true null hypotheses or weights, and to varying distributional p-value models.

2 - A Domain Specific Language to process Causal Loop Diagrams with R

Adrian Stämpfli

Causal Loop Diagrams (CLDs) are a flexible and valuable tool for diagramming the feedback structure of systems. In strategic decision-making and management, especially in the System Dynamics (SD) tradition, CLDs are used (i) to structure complex problems; (ii) to explore complex decision-making situations in participatory modelling processes; (iii) to foster learning among stakeholders involved in the modelling process; (iv) as a basis for simulation models, and (v) to communicate results of simulation studies. As tangible, visual representations of the problem under study, CLDs are an important tool to foster learning and feedback processes among the stakeholders involved in a project. However, the crucial dissemination of those learnings beyond the stakeholders involved in the project is difficult and requires general knowledge about CLDs.

To overcome this problem we present a Domain Specific Language (DSL) that allows to develop small webapps in order to analyze and present structure and behaviour of CLDs using network graphs, behaviour over time graphs and textual descriptions with little programming efforts. We combine CLDs with interactive elements, graphs and textual descriptions, and therefore lower the barriers to learning and increase the attractiveness of CLDs. The DSL approach lowers technical barriers and allows modelling experts with little programming experience to develop such apps. We implemented the DSL in R, an open source programming language and software environment designed for statistical computing, data science and graphics, which is especially well suited to host DSLs.

We developed a first application that uses the DSL to generate small webapps showcasing CLDs of typical work-life-balance conflict situations. We conclude with an outlook on future developments of DSLs to support decision-making processes in Operations Research.

3 - Corporate Governance-Systems & Corporate Social Responsibility-Reporting - An International Comparative Study using Propensity Score Matching

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. Such an additional reporting has not only gotten increasing attention in shareholder-oriented 'exit' systems of corporate governance, but in particular in bank-based insider systems prevalent in continental Europe and Asia and otherwise referred to as 'voice' or 'loyalty' systems. Although the determinants of CSR-disclosure have been analyzed in several empirical studies, this line of research is often lacking an appropriate measure of the scope of CSR-reporting and is restricted to a limited number of conceptually similar regression analyses. Furthermore, existing studies usually focus on one specific country and/or rely on a small sample of firms. Against this background the contribution of our study to the existing empirical literature is threefold: First, we conduct a comparative international study of the determinants of CSR-disclosure in the context of different corporate governance-systems. Our dataset contains the 100 largest listed corporations in the USA ('exit system'), Germany ('voice system') and Japan ('loyalty system') and - based on two sub-samples - covers the years 2003-2007 and 2008-2012 resulting in a total of 3000 firm-year observations. Second, using the guideline developed by the Global Reporting Initiative (GRI) we conduct a detailed content analysis of CSR-reports, annual/integrated reports and firms' websites and construct an aggregated index representing the scope of CSR-disclosure. Our additive index encompasses 69 single indicators contained in the GRI-guideline and referring to the firm's economic performance (3), the environmental behavior (16), labor practices (25), human rights (4), social practices (17) as well as product responsibility (4). Third, in our analysis we account for systematic differences that arise between the firms belonging to different institutional environments. A direct comparison of the intensity of CSR-disclosure in different systems of corporate governance may suffer from a bias due to systematic differences in firm-specific characteristics. In order to achieve a more balanced sample we conduct a propensity score matching based on the firms' core financial and/or corporate governance attributes. By doing so, we aim to reduce the sample selection bias and thus provide more comprehensive and accurate insights regarding the relevance of corporate governance for a firm's CSR-disclosure incentives.

■ WB-14

Wednesday, 11:00-12:40 - ZEU/148/U

Resource Allocation and Selfish Behavior

Stream: Game Theory and Experimental Economics
Invited session

Chair: *Daniel Schmand*

1 - The Secretary Recommendation Problem

Niklas Hahn, Martin Hoefer, Rann Smorodinsky

We revisit the basic variant of the classical secretary problem. We propose a new approach, in which we separate between an agent that evaluates the secretary performance and one that has to make the hiring decision. There are n candidates which arrive one-by-one in random order. The evaluating agent (the sender) signals the quality of the current candidate to the hiring agent (the receiver) who must make an irrevocable decision to take or reject the current candidate. Whenever the two agents' interests are not fully aligned, this induces an information transmission (signaling) challenge for the sender. We study the sender's optimization problem subject to incentive compatibility constraints of the receiver for three variants of the problem. Our results are optimal or near-optimal incentive compatible mechanisms, which recover at least a constant fraction of a natural utility benchmark for the sender.

2 - The Best-Reply Algorithm for Online Resource Allocation Problems

Daniel Schmand, Max Klimm, Andreas Tönnis

We study the performance of a best reply algorithm for online resource allocation problems with a diseconomy of scale. In an online resource allocation problem, we are given a set of resources and a set of requests that arrive in an online manner. Each request consists of a set of feasible allocations and an allocation is a set of resources. The total cost of an allocation vector is given by the sum of the resources' costs, where each resource's cost depends on the total load on the resource under the allocation vector. We analyze the natural online procedure where each request is allocated greedily to a feasible set of resources that minimizes the individual cost of that particular request. In the literature, this algorithm is also known as a one-round walk in congestion games starting from the empty state. For unweighted resource allocation problems with polynomial cost functions with maximum degree d, upper bounds on the competitive ratio of this greedy algorithm were known only for the special cases d=1, 2, 3. In this paper, we show a general upper bound on the competitive ratio of d(d / W((1.2d-1)/(d+1)))(d+1) for the unweighted case where W denotes the product logarithm function. For the weighted case, we show that the competitive ratio of the greedy algorithm is bounded from above by (d/W(d/(d+1)))(d+1).

3 - Interval Scheduling with a Rechargeable Resource

Franziska Eberle, Nicole Megow

We consider a model for interval scheduling with a rechargeable resource. A set of interval jobs with fixed starting times and end times needs to be scheduled conflict-free on a set of identical machines. The goal is to maximize the number or the total weight of the scheduled jobs. Initially, each machine is given an identical amount of a rechargeable resource. During its processing, a job utilizes a job-dependent amount of this resource. While no job is processed on a machine, the corresponding resource can charge at a linear rate. The resource of a machine is neither allowed to exceed the maximal capacity nor to become negative. This model generalizes both, scheduling with a renewable and scheduling with a non-renewable resource, as the linear charging rate allows for a trade-off between these two extremes. A typical application arises in the context of station-based car sharing when scheduling bookings on e-cars with a rechargeable battery.

For single-machine scheduling, we show an optimal polynomial-time algorithm without weights and give a FPTAS in the presence of weights. The multiple-machine case turns out to be considerably harder as the unit-weight case is NP-hard even for a constant number of machines. Based on the optimal single-machine algorithm, we develop an e/(e-1)-approximation for the more general setting where the number of machines is part of the input.

4 - Computing Bayes-Nash Equilibria in Sealed Bid Auctions through Self Play
Stefan Heidekrüger, Martin Bichler

The computation of equilibria via iterative self-play has a long tradition in game theory. While convergence of Fictitious Play to a Nash Equilibrium is guaranteed for specific settings such as 2-player zero-sum games and potential games, there have been a series of negative results about the efficacy of similar methods in the general case due to the demonstrated possibility of cycling dynamics or even convergence to non-equilibrium action profiles. In auction theory and mechanism design, one is especially interested in equilibria of incomplete information games with continuous action spaces, yet game theoretic analysis of self-play methods for this particular class of games has received little attention. In the presented work, we investigate learning behavior of players in continuous action space, n-player Bayesian games under a form of "better response" iterated self-play. In our setting, players' strategies are represented via feed-forward neural networks and strategy parameters are updated in each iteration via a single step of an Evolutionary Strategy numerical optimization algorithm rather than fully solving for a best response to the current opponent strategy profile. We use this algorithm to find equilibrium strategies in sealed bid auctions with limited observability: Players only receive their own reward signals but neither observe their opponents' bids nor do they have explicit knowledge of opponents' prior valuation distributions. We demonstrate that in settings with known analytical solutions, such as single-item First Price and Vickrey auctions, the method indeed computes an approximate Bayes-Nash equilibrium.

■ WB-15

Wednesday, 11:00-12:40 - ZEU/160/H

MIP and MINLP Techniques and Solvers

Stream: Discrete and Integer Optimization
Invited session
Chair: *Tristan Gally*

1 - Designing hashing mechanisms for fast two-row and two-column reductions in mixed-integer presolve
Patrick Gemander, Weikun Chen, Ambros Gleixner, Robert Lion Gottwald, Alexander Martin, Dieter Weninger

The core tool of modern mixed-integer optimization are solvers like SCIP, Gurobi or CPLEX. In each of these solvers, a large array of fast simplification techniques are being run during a phase called "presolve" before the actual optimization process starts. Despite their speed and often, simplicity, these methods can have significant impact on the solvability of a given problem. In order to guarantee short runtimes, presolving techniques mostly focus on a single constraint or variable. First steps towards multi-row presolving techniques have been made in the form of detecting parallel rows of the constraint matrix. However, even techniques that consider just two rows or columns need to be applied quadratically often.

In this talk, we will look at a number of two-row and two-column presolving techniques and present hashing mechanisms which allow us to counteract the problem of having to apply them to quadratically many pairs of rows or columns of the constraint matrix. The basic idea is to search through the problem and punctually hash information to find promising pairs of rows or columns to which the presolving techniques will then be applied to. Additionally, we present improvements on some of the presolving techniques themselves, where set-packing constraints are being used to further strengthen the results without negatively impacting the runtime.

These methods have been implemented in the MIP solver SCIP and we will present the results of computational experiments where the new methods have been applied to instances of the MIPLIB 2017.

2 - Applicability of a PADM heuristic and an exact Decomposition Branching approach for MIPs with block structure
Katrin Halbig, Dieter Weninger, Alexander Martin

Many real world mixed-integer linear problems possess a block structure and can be decomposed into loosely coupled blocks. We discuss two methods exploiting such a structure. At first a penalty alternating direction method (PADM) for computing primal heuristic solutions is presented. A PADM is a generalization of the well-known feasibility pumps. Subsequently, we will introduce the Decomposition Branching method, which uses decompositions with linking constraints. This method is a branch-and-bound algorithm, which branches on blocks instead of variables. The focus will be on the advantages and drawbacks of this technique. For both methods the applicability and practicability on different problem classes arising for example in supply chain management is demonstrated and computational results are presented.

3 - A Computational Study Of Perspective Cuts
Ksenia Bestuzheva, Ambros Gleixner, Stefan Vigerske

Semi-continuous variables are variables with (possibly disconnected) domains that depend on the value of a binary indicator variable and reduce to one value when the indicator variable is set to zero. These structures are typically used for modeling systems where some elements have distinct "on" and "off" states. We consider convex functions that depend on semi-continuous variables with a common indicator variable. Naive linear programming relaxations do not make explicit use of the indicator variable dependence. A stronger formulation can be obtained by applying the perspective formulation, which algebraically describes the convex hull of the union of two sets that correspond to possible values of the indicator variable. A convex constraint built with the use of this reformulation can be enforced by separating what are called perspective cuts.

While the benefits of perspective cuts are well known for specific problem classes, we are not aware of any empirical studies that evaluate their applicability and computational impact over large, heterogeneous test sets in general-purpose solvers.

This talk presents a computational study of perspective cuts within SCIP, a branch-and-cut based MINLP solver. Our implementation detects functions of semi-continuous variables in MINLPs and uses the perspective formulation in order to derive cutting planes, which are then applied for the separation of solutions of LP relaxations. The results of computational experiments are presented which compare the performance with perspective and standard gradient cuts. Perspective cuts are shown to reduce the mean solving time and allow for more instances to be solved within the time limit of one hour.

4 - What's new in the Xpress Solvers
Tristan Gally

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

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■ WB-16

Wednesday, 11:00-12:40 - ZEU/250/Z

Local error bounds and their applications

Stream: Control Theory and Continuous Optimization
Invited session
Chair: *Nico Strasdat*

1 - On local Lipschitzian error bounds and applications
Mario Jelitte

In recent decades, much attention has been paid on local Lipschitzian error bounds and their applications. Their applicability in the design of numerical algorithms for various kinds of mathematical programs is nowadays well known. Often, it can be difficult to confirm that some function provides an error bound for a given set. To simplify this task for some cases, we recall a result of Izmailov et al., where error bounds were analysed for the solution set of a generic unconstrained equation. We will extend their result in multiple ways and introduce applications that go beyond the analysis of certain numerical algorithms.

2 - A technique for adjusting dual iterations in the presence of critical Lagrange multipliers.
Wladimir Scheck, Andreas Fischer, Alexey Izmailov

In constrained optimization, it is well known that critical Lagrange multipliers are specially attractive for dual sequences generated by primal-dual Newton-type methods. This phenomenon is the reason for the slow convergence in such circumstances. The existence of critical multipliers is quite common if the set of Lagrange multipliers associated to the primal solution is not a singleton. Even for certain Newton-type methods developed for tackling cases of nonisolated solutions, the effect of attraction to critical multipliers still exists. For

equality-constrained optimization problems, we present a universal local technique to obtain an approximation of a Lagrange multiplier of the same "quality" as the primal approximation that stays away from the critical multiplier in question. When combined with stabilized or regularized Newton-type methods, this allows to significantly reduce the domain of attraction for this critical multiplier. The accelerating effect on the convergence speed of this technique is demonstrated by numerical experiments for stabilized sequential quadratic programming, the Levenberg-Marquardt method, and the LP-Newton method.

3 - On Newton-Type Methods for Generalized Equations

Diethard Klatte

In this talk, we study Newton-Type methods for generalized equations, i.e., for the problem of finding a zero of the Minkowski sum of a function f (usually supposed to be locally Lipschitz) and and a multi-valued mapping M. Generalized equations appear for example as optimality conditions in optimization problems with differentiable data or in variational inequalities with Lipschitz data. Classical and new approaches of such methods are presented. We analyze superlinear local convergence of the methods under consideration, in particular we extend convergence results via so-called Newton maps from equations to generalized equations both for linear and nonlinear approximations of f. Since in methods of this type the generation of the iteration sequence is not unique in general, we look for conditions guaranteeing for any choice of iteration points superlinear convergence. The talk is based on a joint paper with my colleague Bernd Kummer, Humboldt University Berlin, see D. Klatte, B. Kummer, "Approximations and Generalized Newton Methods", Mathematical Programming, Series B, Vol. 168 (2018) 673-716.

4 - A Newton-type method for the solution of complementarity problems

Nico Strasdat, *Andreas Fischer*

Recently, a Newton-type method for the solution of Karush-Kuhn-Tucker system has been developed, that builds on the reformulation of the system as system of nonlinear equations by means of the Fischer-Burmeister function. Based on a similar idea, we propose a constrained Levenberg-Marquardt-type method for solving a general nonlinear complementarity problem. We show that this method is locally superlinear convergent under certain conditions which allow nonisolated and degenerate solutions.

■ WB-17

Wednesday, 11:00-12:40 - ZEU/255/Z

Special Session on Business Applications I

Stream: Business Track
Invited session
Chair: *Michael Boegl*

1 - Trends and Challenges in Real Life Production Problems - Examples and Use Cases

Michael Boegl, *Anna Gattinger*, *Manuel Schlenkrich*, *Ionela Knospe*, *Martin Pinzger*, *Roman Stainko*

The market pressure forces companies to improve production efficiency and therefore motivates them to employ computer assisted planning systems for their production-planning problems. Depending on the field of activity, those production planning problems can be completely different. In this work we describe two different types of production planning problems, characterize their requirements and illustrate the respective solution approach, which we implemented to solve them.

The first type of problem is the planning of machine operations. Given is a machine, which must perform a certain task, i.e., cutting wooden boards, under consideration of given constraints. It should do that in a way to minimize scrap or maximize profit. The machine can perform a fixed set of operations. Given the current product configuration and the available raw material, which is scanned as it enters the machine, the machine should be operated so that the overall goal, e.g., of minimizing waste, is met. As the machine operates within a given cycle time, it must be guaranteed that a valid solution is readily available when the machine performs the next operation. Often this is goal is more important than the quality of a solution. At this level of planning it must also be guaranteed that the machine can perform the operation within its degrees of freedom.

Another type of problem is the planning of the master production schedule. Here, the requirements are different compared to the former case. There is no tight cycle time, i.e., the calculation of the plan is allowed to take some time (minutes or even hours). Often it is required that the user can modify/adapt the automatically computed plan manually. For these type of problem the major challenges are the large problem sizes and the desire of the stake holders for detailed plans for long planning horizons, i.e., hundreds of orders with dozens or hundreds of activities/operations must be planned on dozens of machines. Additionally, customer specific constraints must be considered, too, e.g., alternative machines, resource pools, technology requirements, or similar constructs, which further increase the complexity.

We developed optimization software for both types of problems. In this work we show real-life use cases for each type of the above problems and illustrate our solution approaches. The implemented solution approaches include tree-based search/enumeration methods, fast heuristics, pre-calculation of decision tables, and neighborhood based metaheuristic search methods. Where appropriate the given problem is decomposed into sub-problems, which can be handled more efficiently and the solutions to those sub-problems are then assembled to yield a complete solution.

2 - Heuristic search for the real-world 3D stock cutting problem

Katerina Klimova, *Una Benlic*

Stock cutting is a well-known optimisation problem arising from important practical applications. Stock cutting is the problem of cutting standard-sized pieces of stock material (e.g., paper rolls or sheet metal) so as to minimize the amount of wasted material. According to a study conducted by a leading international packing company, 50% of the packing volume is air. Considering that only Amazon itself dispatched over 5 billion items in 2017, the potential for packing improvement is massive. In the ideal case scenario, each order would be packed into a custom-made box according to its dimensions. However, this is generally impossible from the practical stance as the packing process would get significantly slower and costly - a suitable box would need to be produced for each item.

The purpose of this work is to help businesses reduce the amount of empty packing volume, by determining the three dimensions for a given finite number of box types available to pack a given set of items. As stock cutting is known to be NP-hard, we propose a modified Adaptive Large Neighbourhood Search heuristic based on different repair and destroy move operators. The approach alternates between two phases, where the first phase is based on two destroy operators (item cluster removal and best removal) and a repair operator which places an item to its most suitable box. Adaptive Large Neighborhood Search is then applied to diversify the search through the use of 5 additional move operators. These include a random operator, and operators considering only a subset of constraints. The reason behind the variety of tactics is to provide an effective search across a wide range of data instance with different degrees of variation in item dimensions.

The performance of the proposed approach was evaluated using real-world data instances based on historical orders, where each order is defined by the number of shipped items, the dimensions of items and boxes, and the number of available box types. The sizes of the data instances range from a few thousand up to more than five million items, while the available number of box types ranges from three to twenty. When comparing our results with the box suites used in a real-world scenario, we notice up to 50% of improvement in the total cost and a 22% decrease in shipped air on average. The runtime of the proposed heuristic ranges from several minutes for small datasets up to 90 minutes for the largest datasets, which fits into the business requirements.

3 - Solving a Rich Intra-facility Steel Slab Routing and Stacking Problem

Biljana Roljic, *Fabien Tricoire*, *Karl Doerner*

The steel industry faces particular challenges such as high throughput volumes, complex handling processes, and increasing quality expectations. Integrated steel plants carry out all steps for primary steel production from smelting iron ore to rolling products into finished shapes. In this work, we study the intra-facility logistics of solidified liquid steel at its raw stage, so-called steel slabs.

Crucial tasks of steel producing plants are the transportation and intermediate storage of steel slabs. Steel slabs are heterogeneous semi-finished products that are produced at continuous casters. The cast steel must pass multiple treatment stages, involving scarfing, resting,

and temperature-regulating handling processes, all of which are carried out at different locations inside the plant. Each treatment stage generates transportation requirements, which in turn trigger stacking and sorting processes. We are given a fleet of straddle carriers, which can not only transport multiple steel slabs at once but also can carry out loading and stacking operations autonomously due to an integrated crane. Once a steel slab passes through all required treatment stages, it is brought to the mill, where it is transformed into a finished product, a so-called coil.

Within the scope of intra-logistical optimization efforts, the emphasis of our study is twofold. First, we develop a transportation model that addresses the routing of steel slabs inside the plant, which corresponds to a capacitated vehicle routing problem (CVRP). We model our solution approach such that we comply with restrictions imposed by the real world problem setting, however, we also yield more opportunities for optimization by exploring restrictive business policies. Second, we address the stacking and sorting of work-in-process steel slabs during the time they are buffered in large storage yards, waiting to be fed into the next stage of the production process. The stacking of steel slabs as part of a vehicle's pickup operation corresponds to a block relocation problem (BRP) with additional constraints. We solve the problem by means of a large neighborhood search, addressing the routing of the steels slabs, and a tailored stacking heuristic, optimizing the stacking and sorting requirements.

By developing a combined approach that optimizes the transportation and stacking of steel slabs, cost-cutting potentials and efficiency improvements can be revealed. In addition to validating our solution approach by solving real-world data sets from the past, we applied our method in real-time operation at our industrial partner's plant. The online application of our model entailed performing live-tests where we optimized the routing and stacking of steel slabs during a three-hour-long operational period on a rolling horizon. The model was applied and validated by transportation dispatchers in real-time and continuous model improvement was administered.

4 - Transporter allocation in an optimized harvesting chain
Neele Leithäuser, Neil Jami

With agricultural businesses becoming less and larger, the resource management receives a new focus. Farming operations can no longer be planned merely upon experience and rules of thumb. Instead, farm managers or contractors have to schedule their resources, such as machines and staff, efficiently in order to be competitive. One example for a resource-intensive logistic operation is the forage harvesting process. In this operation, so called self-propelled forage harvesters harvest and shred crops (e.g. corn). Transporters carry the resulting silage to pits, where it will be compacted, covered, and stored. It can then be used as cow food or in biomass plants. Since the harvesters do not have bunkers that can work as buffers, the harvester can only work if a transporter is driving in parallel to it, which can immediately be filled with the silage. The transporters are periodically filled, drive to the silage pit, dump their load and go back to the field. From a day-ahead perspective, the logistic manager of a large harvesting operation has to take the following decisions • Which field's biomass should be transported to which silage pit? • Which harvester should work on which fields and in which order? • Which transporters should work on which fields and in which order? We implemented a multi-criteria day-ahead planning tool for farming operations based on the example of forage harvesting. We executed the above decision steps in a hierarchical manner with respect to the total operation makespan, the required number of transporters and the transportation costs. In this talk, we will focus on the problem of allocating transporters to harvesters. Since the harvesters are the most expensive resource, it is desirable to keep them busy. If the transporting capacity is not sufficient, this results in harvester idle time. However, the overall impact of undercapacities depends on many factors, such as field sizes, distances, and load balance between harvesters. It is hence wise to trade-off the investment in transporter resources and their allocation with the reduction of operation time. From a theoretical point of view, it is already NP-hard to decide whether an allocation without harvester idle times exists for a given heterogeneous transporter fleet. It is correspondingly harder to find such an allocation with minimum cardinality or minimum makespan. For uniformly sized transporters, these problems become easier, although not trivial.

Wednesday, 14:00-15:40

■ WC-02

Wednesday, 14:00-15:40 - POT/051/H

Loading Problems

Stream: Logistics and Freight Transportation
Invited session
Chair: *Sophie Parragh*

1 - The parallel stack loading problem minimizing the number of reshuffles in the retrieval stage
Sigrid Knust, Sven Boge

We consider the parallel stack loading problem (PSLP) with the objective to minimize the number of reshuffles in the retrieval stage. Since in the PSLP the incoming items have to be stored according to a fixed arrival sequence, some reshuffles cannot be avoided later on. We study two surrogate objective functions (number of unordered stackings, number of badly placed items) to estimate the number of reshuffles and compare them theoretically as well as in a computational study. For this purpose, MIP formulations and a simulated annealing algorithm are proposed.

2 - The 3L-VRPTW with advanced real-world loading constraints
Corinna Krebs, Andreas Bortfeldt

Many vehicle routing approaches ignore complex loading constraints. Given automated order and planning systems, detailed characteristics of items and vehicles are becoming available. We consider the three-dimensional loading vehicle routing problem with time windows (3L-VRPTW), which addresses the combined optimization of the vehicle routing problem and container loading problem. In this problem, three-dimensional cuboid items have to be transported from a central depot to a given set of customers using a homogeneous fleet of vehicles. Each route must be provided with a feasible packing plan taking different packing constraints into account. In addition, customer time windows have to be considered. The objective is to minimize the number of vehicles and the total routing costs.

In the proposed hybrid approach, an Adaptive Large Neighborhood Search is used for solving the routing subproblem. The procedure is combined with a Deepest-Bottom-Left-Fill algorithm to ensure the feasibility of the obtained solutions with respect to the loading subproblem.

The focus of this presentation is on the examination of loading constraints currently considered in the literature regarding their purpose and issues. As a result, new improved definitions and implementation variants such as of stacking and stability constraints are introduced in order to provide a more realistic formulation. Their impact on the objective function value is tested by using well-known instances.

3 - Unloading strategies for a stacking problem with item families
Sven Boge, Sigrid Knust

In this work, we consider the process of unloading items in a warehouse. The items are stored in stacks and moved by a crane. Each item is associated with a family indicating the main attribute (type) of the item. For a given subsequence of these item families, it has to be decided which item of each requested family shall be unloaded from the warehouse using the least possible number of crane moves to save time and cost. Algorithms for this problem have to decide which items of a family should be used at which point in the retrieval sequence and where incoming and blocking items should be located. Heuristics and metaheuristics for the unloading problem are proposed and compared to strategies which are currently used in the warehouse of a German company producing work plates. Furthermore, a novel MIP formulation is presented and compared to MIP formulations in literature. Computational results are presented for a large data set of randomly generated instances according to the setting in the warehouse and two smaller real-world data sets.

4 - Dynamic programming and local search for container relocation
Fabien Tricoire, Dominique Feillet, Sophie Parragh

The unrestricted block relocation problem is an important optimization problem encountered at container terminals, where containers are stored in stacks. It consists in determining the minimum number of container moves so as to empty the considered loading bay following a certain retrieval sequence. A container move can be either the retrieval of a container or the relocation of a certain container on top of a stack to another stack. The latter types of moves are necessary so as to provide access to containers which are currently not on top of a stack. They might also be useful to facilitate future removals, and to avoid additional relocations later on.

In this work, we propose the first local search type improvement heuristic for the block relocation problem. It relies on a clever definition of the state space which is explored by means of a dynamic programming algorithm so as to identify the locally optimal sequence of moves of a given container. The sequence of relocations of each container can then be optimized individually. Experimental results on large benchmark instances reveal unexpectedly high improvement potentials (up to 50%) compared to results obtained by state-of-the-art constructive heuristics.

■ WC-03

Wednesday, 14:00-15:40 - POT/081/H

GOR Dissertation Award Winner Presentations

Stream: GOR Award Winner Presentations
Invited session
Chair: *Peter Letmathe*

1 - Presolving techniques and linear relaxations for cumulative scheduling

Stefan Heinz

In the mathematical optimization community the term scheduling usually describes the computation of a sequential plan for a set of jobs w.r.t. a set of side conditions such as precedence requirements and resource restrictions. Thereby, a certain objective should be fulfilled. The sequential plan can be an ordering of the jobs or in case of this presentation a schedule which assigns a start time to each job. We focus on the cumulative constraint which can be used to describe a relationship between a renewable resource and non-preemptive jobs which require a certain amount of the resource during their execution. For a systematic approach, we formally define energy-based propagation algorithms, a class of propagation algorithms for these constraints. These inference algorithms for the cumulative resource structure use volume arguments to infer bounds on the start time and the completion time of a job. In addition, we present a primal and dual inference technique for these constraints.

2 - Analysis and optimization of urban energy systems

Kai Mainzer

Cities and municipalities are critical for the success of the energy transition and hence often pursue their own sustainability goals. However, there is a lack of the required know-how to identify suitable combinations of measures to achieve these goals. The RE'ASON model allows automated analyses, e.g. to determine the energy demands as well as renewable energy potentials. In the subsequent optimization of the respective energy systems, various objectives can be pursued - e.g. minimization of discounted system expenditures and emission reduction targets. The implementation of this model employs various methods from the fields of geoinformatics, economics, machine learning and mixed-integer linear optimization. An application of the model, by using stakeholder preferences and multi-criteria decision analysis, shows that the transformation of the urban energy system to use local and sustainable energy can be the preferred alternative from the point of view of community representatives.

3 - Optimization in outbound logistics

Stefan Schwerdfeger

The ongoing trends towards lean production, an increasing parcel volume, and just-in-time logistics demand for a more and more efficient logistics. In this difficile environment, the thesis is dedicated to operational and tactical planning tasks of the outbound logistics. More precisely, we investigate order picking, transportation, and workload balancing problems and provide crucial practical as well as theoretical insights. Problems motivated from business practice were transferred into mathematical programs, and, based on their complexity status, appropriate algorithms were provided. Those results were finally used to reveal managerial aspects to bridge between theoretical insights and the practical application. While the developed procedures can be applied to handle tasks at the operational and tactical level, such as the sequencing of picking orders or the scheduling of truck deliveries, the observations made within our simulations are valuable at the strategic level, e.g., to size the pick face or to place a cross dock. To conclude, our investigations expose significant savings enabled by tailor-made algorithms which underline the importance of the diffusion and the application of optimization procedures in practice.

4 - Incorporating Differential Equations into Mixed-Integer Programming for Gas Transport Optimization

Mathias Sirvent

Natural gas is one of the most important energy sources. The corresponding gas transport optimization problems involve discrete decisions to switch network elements and differential equations due to the physical behavior of gas. The scientific contribution of this thesis is twofold. First, three new global algorithms are presented. 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 equations. In this sense, promising numerical results for stationary gas transport optimization are shown. Second, an instantaneous control algorithm for transient gas network optimization is presented. A new discretization scheme that allows to use mixed-integer linear programs inside of the instantaneous control algorithm is developed for the example of gas. Again, promising numerical results are shown.

■ WC-04

Wednesday, 14:00-15:40 - POT/106/U

Industrial Applications of Optimal Control

Stream: Control Theory and Continuous Optimization
Invited session
Chair: *Marc Steinbach*

1 - Model-based Optimal Feedback Control for Microgrids

Robert Scholz

In the context of the energy transition, the use of renewable energy sources (RES) has increased significantly over the last years. Most of the RES are small-sized and therefore connected to medium or low voltage grids. The high number of RES is a rising challenge for the current control paradigm of the utility grid. Microgrids are small-sized electrical networks with heterogeneous components. They are considered to become a key technology to facilitate the integration of RES, because they allow to cluster local components as a single controllable part of a larger electrical network.

However, the effective operation of microgrids is extremely challenging. Current controllers are not able to compensate the unstable power input of RES without the usage of batteries, which causes high infrastructure costs. The stable and efficient operation of microgrids requires novel control strategies. From a mathematical point of view, this is a challenging task: the dynamics of the interconnected components are highly nonlinear and stiff; the disconnection of interruptible loads leads to integer variables and the system is constantly in a transient phase. In addition, dynamical effects on different time scales have to be considered.

Nonlinear model predictive control (NMPC) is a promising approach to address these issues. A dynamic model is used to predict and optimize the performance of the microgrid for a sufficiently long prediction horizon. To perform the optimization, we apply the direct multiple shooting discretization in combination with a structure exploiting SQP method. We enable real time feasibility and high feedback rates by the multi level iteration scheme and an online active set strategy for the quadratic subproblems.

In this talk we propose a NMPC control strategy for microgrids and present numerical results. We define test cases based on a cooperation with Prof. Marija Ilic from the Laboratory for Information & Decision

Systems (MIT). The microgrid is represented by an ordinary differential equation system and comprises generators, transmission lines and loads. The proposed NMPC controller acts on a secondary level and provides set points for the primary controllers of the generators.

2 - Towards Optimal Control of an Industrial Multi-Modal Chromatography Process

Dominik Cebulla, Christian Kirches, Andreas Potschka

Separation of proteins plays a significant role in the development and production of pharmaceuticals, where an economic objective has to be maximized while ensuring a high quality of the product. Over the last few decades, multi-modal (or mixed-mode) chromatography has emerged as a powerful tool to fulfill this task, primarily because of its higher selectivity compared to single-mode techniques, such as ion exchange chromatography.

In this talk we describe the basic principles of a chromatographic process and present a mechanistic nonlinear partial differential equation model for multi-modal chromatography. Furthermore, we highlight challenges regarding the model calibration.

The purification process is the most expensive step within the production of pharmaceuticals since the product has to be of high purity. Hence we identify a high potential of reducing these costs, yet maintaining (or improving) the purity level of the product.

We conclude the talk with numerical results.

3 - Application and experimental results of model predictive control for a solar thermal system for building climate control

Adrian Bürger, Parantapa Sawant, Markus Bohlayer, Angelika Altmann-Dieses, Marco Braun, Moritz Diehl

The subject of this talk is the application of a Model Predictive Control (MPC) strategy for a building climate system operated at Karlsruhe University of Applied Sciences. The system consists of an adsorption cooling machine driven by solar thermal energy and of heat and cold storages. As it is typical for renewable energy systems, the system strongly depends on external factors such as solar irradiation and ambient temperature, which are forecastable but underlie disturbances. Further, the system is subject to constraints such as limits on the number of machine switches, machine operation conditions etc. which need to be incorporated in the control strategy.

Due to the switching behavior of the installed machinery, an MPC application for the system results in Mixed-Integer Optimal Control Problems (MIOCPs) that need to be solved on suitable time scales for real-time control of the system. The algorithm applied for solving the Mixed-Integer Non-Linear Programs (MINLPs) arising from discretization of the MIOCPs relies on decomposing the MINLP into a sequence of subproblems of which each one is easier to solve than the original problem, in particular Non-Linear Programs and a Mixed-Integer Linear Program. The latter one is a Combinatorial Integral Approximation problem, which can be solved efficiently by a tailored Branch-and-Bound method.

The talk will provide insight on both the applied algorithms and the software used for implementing the control strategy and discuss measures that are taken for runtime reduction of the implemented methods. After that, experimental results obtained from system operation using MPC are presented and benefits and future challenges are discussed.

4 - Abs-Linear Learning by Mixed Binary Quadratic Optimization

Andreas Griewank, Angel Adrian Rojas Jimenez

We consider predictor functions in abs-linear form, which generalize neural nets with hinge activation. To train them with respect to a given data set of feature-label pairs, one has to minimize the average loss, which is a multi-piecewise linear or quadratic function of the weights, i.e. coefficients of the abs-linear form. We suggest to attack this nonsmooth, global optimization problem via successive piecewise linearization, which allows the application of mixed binary convex quadratic optimization codes amongst other methods. These solve the sequence of abs-linear model problems with a proximal term.

■ WC-05

Wednesday, 14:00-15:40 - POT/112/H

Charging electric vehicles

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Natalia Kliewer*

1 - Charged up? Preferences for Electric Vehicle Charging and Implications for Charging Infrastructure Planning

Stefanie Wolff, Reinhard Madlener

Electric mobility is at the crossroads of the sustainable energy and sustainable mobility transitions. Specifically, the mobility transition includes changes in the individual mobility behavior. The recharging of electric vehicles (EV) should adapt to both the energy and the mobility transition. From a user perspective, EV battery charging takes considerably longer than filling the gas tank. Thus, EV charging will have to be adjusted in order to better fit user expectations, needs, and behavior. From a business perspective, use cases for charge point operators are often still missing. The necessary EV infrastructure investments are high and the revenue streams are often still too low. Also, it is not clear who the preferable actors are for installing and running EV infrastructure; it may be car manufacturers, municipalities, energy companies or entrepreneurial charge point operators. Consequently, it is crucial to better understand the charging preferences of EV drivers. Therefore, we assess EV drivers' willingness to pay (WTP) of six different attributes of the charging process: place of charging, duration, technology, waiting time for a charging spot to become available, share of renewables, and cost per month. Due to the low number of current EV users in Germany, analyzing consumers' EV charging infrastructure preferences and their WTP for them based on real usage data is challenging. Thus, we gathered data through a Discrete Choice Experiment (DCE) conducted in Germany. We asked respondents to imagine that they use an EV in their daily routines and confronted them with two hypothetical choice bundles for certain attributes of the EV charging process. The choice bundles are described by the aforementioned six attributes that are defined by levels that vary between choice scenarios (e.g., duration takes on the four levels 10 min, 30 min, 4 h, or 8 h). The respondents repeated these choice scenarios 12 times with randomly assigned levels. This design allows us to account for differences between individual choice behavior since the respondents maximize their utility by choosing a particular charging solution which represents their individual tradeoffs between attributes and choices. We analyzed the data using fixed-effects logit models to exploit the repetitiveness of choices. The respondents preferred charging at home to at work to at the roadside, inductive to cable-charging, with a higher share of renewables, with shorter waiting times and shorter durations, at the lowest costs. We detect changes in WTP for lower charging durations at specific time intervals, e.g., for a reduction in charging time from 8 h to 7 h, consumers are willing to pay around 8 EUR /month; whereas from 8 h to 10 min, consumers are willing to pay around 70 EUR /months for all charging processes. Avenues for futures research of individual choice behavior could be the integration of vehicle-to-grid and smart home, e.g., combining photovoltaic systems with EVs.

2 - Practical Evaluation of a Smart Charging Heuristic

Oliver Frendo, Nadine Gaertner

Smart charging is motivated by a rising number of electric vehicles (EVs) and insufficient electrical infrastructure including undersized power lines. Precise charge scheduling is limited by missing data and by complex behavior in the practical execution of charging plans.

In this work, we use a simplifying heuristic for the scheduling of charging plans. For example, the heuristic assumes the state of charge (SoC) is known. However, in practice it is currently not accessible in a standardized way for all EVs. Additionally, the heuristic does not consider latency and loss of precision caused by the protocol (OCPP 1.6) used to transmit charging plans to charging stations. Lastly, the heuristic assumes EVs charge using constant current throughout the charging process. In practice, the current drawn by the EV decreases after reaching a certain SoC to extend battery life. We address the following research question: How applicable are the produced charging schedules and what are effects of the simplifying assumptions?

In this work, we analyze data generated during a practical trial involving a charging infrastructure with an undersized connection and a diverse set of EVs. We evaluate to what extent actual current measurements deviate from charging plans produced by the heuristic. Insights

gained during the practical trial show how the heuristic may be refined to improve infrastructure utilization.

3 - Primal-Dual Greedy Heuristics for Large Scale Electric Vehicle Recharging Infrastructure Planning

Paul Göpfert, Stefan Bock

In this talk we consider algorithms for the determination of an efficient network of recharging stations for long distance traveling. A recent Branch and Cut Approach proposed by the authors 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. A computational study shows, that the obtained bounds on the optimal objective value are indeed very tight. However, these high quality bounds are hard to turn into good feasible integral solutions especially on large scale networks. Therefore, we provide first computational results for the combination of a classical (primal) greedy algorithm with a dual greedy heuristic, which derives its decisions from the fractional optimal solution of the LP-relaxation.

4 - Location Planning of Charging Stations under Spatial Limitations and Power Grid Constraints

David Rößler, Nils Olsen, Natalia Kliewer

For a cost-efficient use of electric buses in public transport, the charging stations must be located within the route network in such a way that required deadhead trips are as short as possible. To overcome range limitations of electric buses, detours to charging stations are necessary. Locations of charging stations directly influence resulting vehicle schedules. Hence, location planning and vehicle scheduling have to be considered simultaneously in order to open up optimization potentials. In previous implementations of a simultaneous solution algorithm, it was mostly assumed that, at charging stations, no capacity restrictions must be observed. Thus, parallel charging of multiple buses was constrained only indirectly through the input schedule. However, capacity restrictions concerning the space usage of a charging station and regarding stability of the local distribution grid do apply. While, in urban areas, space limitations are of greater importance for the layout of opportunity charging stations, logically situated in more densely built-up areas, grid stability concerns are becoming more relevant for the parallel charging of multiple vehicles at the bus depot. An approach to capturing these limitations in the time space network (TSN) model for the electric vehicle scheduling problem (E-VSP) is presented. For this, we introduce space capacity constraints, integrate an optimized load scheduling (LM), and demonstrate their effects on the feasibility of vehicle rotations in the resulting solutions.

■ WC-06

Wednesday, 14:00-15:40 - POT/151/H

Industrial optimisation 1

Stream: Energy and Environment
Invited session
Chair: *Matthew Schmidt*

1 - On optimisation of transition nuclear fuel cycles

Roman Cada

In the talk we first introduce the problem of nuclear fuel reload pattern optimisation. In general it is a very complex problem. From mathematical point of view it basically combines combinatorial optimisation and systems of partial differential equations.

The used fuel types are usually replaced by a new type after several years (because of increasing power of the reactor, increased enrichment, improved construction etc.). The problem of designing reload patterns by using a mixture of old and new types (besides using fresh and depleted fuel assemblies) becomes even more complex as different types need to satisfy different criterions. The aim of the optimisation is to design several consecutive fuel cycles with increasing number of assemblies of new fuel type(s) so that in the last cycle of the series only assemblies of the new fuel type(s) are used.

We particularly focus on recent development and tests of methods for this problem.

2 - Determining an optimal energy demand range within master production planning

Hajo Terbrack, Thorsten Claus, Frank Herrmann

Energy consumption, respectively the costs involved, have an increasingly stronger impact on the production costs. Simulation experiments for some real world applications show high variation in energy demand over time leading to planning uncertainty for electricity suppliers. Thus, we propose that a manufacturing company and an electricity supplier agree on a price that applies to a consumption interval. The price increases with the interval width. Energy consumption outside the interval leads to considerable price premiums. The company thus profits from the favorable prices and the energy supplier gains planning security. The energy industry is working on similar price models. We develop a method based on hierarchical production planning - as proposed by Hax and Meal, among others, in 1975 - with which the manufacturing company can determine suitable interval limits. Such hierarchical production planning consists of the levels scheduling, lot sizing and master production scheduling. Since the latter one is generally accomplished over a horizon of multiple months, we determine this energy demand range on this level. We assume a linear optimization model for master production scheduling and extend a basic model without shortage frequently used in research by constraints to restrict the usage of energy within the energy demand range. In the classical model for master production scheduling capacity load factors are used to anticipate the capacity demand on the next two planning levels (i.e. lot sizing and scheduling) and especially on the shop floor. We transfer this concept to the energy demand and introduce energy demand factors. In addition, we extend the objective function (which has to be minimized and usually consists of costs just for inventory and additional capacity usage) by costs for the width and height of the energy demand range. In this study we limit ourselves to the consideration of the master production scheduling (an implementation of our results into a multi-stage PPC simulation is planned for future extensions). We show that some real world applications have different high energy demand factors which cause high variations in energy demand. In the simplest case this energy demand can be smoothed by higher inventory levels. These are rather exceptions since solutions tend to consume capacity evenly and at the same time on a high level. Numerical results show that solutions of the new model and the classical one are structurally very different. As said earlier, the demand energy factors just anticipate the real energy consumption. In order to integrate the influence of this error, production is carried out according to this planning result with random energy consumption. Due to high safety stocks, we ensure a small deviation of the energy demand range. First numerical results show that this approach is suitable for determining interval limits for energy consumption and reduces energy consumption, resp. its costs, significantly.

■ WC-07

Wednesday, 14:00-15:40 - POT/251/H

Technologies of Artificial Creativity

Stream: OR in Engineering
Invited session
Chair: *Tim Müller*

1 - Truss Topology Design of Unstructured Lattices for Additive Manufacturing

Christian Reintjes, Michael Hartisch, Ulf Lorenz

The decisive development of powder-based additive manufacturing (AM) processes in recent years has significantly increased the freedom of geometry in production. This has made it possible to produce much more complex unstructured lattices. These new manufacturing possibilities require the development of new optimization methods, which are specially adapted to AM in order to exploit the full lightweight construction potential. This work presents a toolchain to use a mixed integer program (MIP) as a truss topology design for AM. The link between the mathematical optimization model and AM is a specially developed CAD tool. It reads out the results of the mathematical model and generates a consistent CAD assembly including a design history and AM system-specific data formats. This enables a subsequent numerical simulation of the linear-elastic material behavior with the finite element method and the use of AM. This work is intended to contribute to strengthening the field of operations research in the engineering sciences and to give engineers access to the use of mathematical modelling. The goal is to integrate mathematical optimization as a development and optimization tool for lightweight construction into the

process chain of AM. The mechanical modeling background for the MIP is introduced. The complete toolchain is presented, as well as a example instance manufactured by selective laser sintering.

2 - Optimized Design of Thermofluid Systems Using the Example of Mold Cooling in Injection Molding

Jonas Benjamin Weber, Michael Hartisch, Ulf Lorenz

For many industrial applications, the heating and cooling of fluids is an essential aspect. Systems used for this purpose can be summarized under the general term "thermofluid systems". As an application, we investigate industrial process cooling systems that are used, among other things, for mold cooling in injection molding. The systems considered in this work consist of interconnected individual air-cooled chillers and injection molds which act as ideal heat sources. In practice, some parts of the system are typically fixed, while some components and their connections are optional and thus allow a certain degree of freedom for the design. Therefore, our goal is to find a favorable system design and operation regarding a set of a-priori known load scenarios. In this context, a favorable system is one which is able to satisfy the demand in all load scenarios and has comparably low total costs. Hence, an optimization problem arises which can be modeled using mixed integer non-linear programming. The non-linearity is induced both by the component behavior as well as by the general physical system behavior. As a proof of concept and to complete our work, we then conduct a small case study which illustrates the potential of our approach.

3 - Optimization of Pumping Systems for Buildings: Experimental Validation of Different Degrees of Model Detail on a Modular Test Rig

Tim Müller, Philipp Leise, Lena Charlotte Altherr, Peter Pelz

The development of optimization programs always requires a model of the underlying mechanism, in our case a physical process. These models determine the quality and usability of the optimization results: Only if they describe the real processes accurately, it is valid to apply the results in practice and to call them a technical optimum. However, a trade-off between a high degree of detail and short solving time is necessary. In addition, the models are always subject to uncertainty, which is the motivation for robust or stochastic optimization. Due to this, in engineering disciplines like product development or system planning, solutions are typically validated: The proposed solutions (whether derived from conventional design techniques or mathematical optimization) are tested for their performance and feasibility by means of simulations and experiments. In this contribution, we demonstrate the steps of modelling, optimization and validation using the example of downscaled, decentralized pumping systems for high-rise buildings. These pumping systems, also called booster stations, are necessary to increase the pressure and thus to supply higher floors with sufficient water. As shown in [1], the decentralization of the pumps and the mathematical optimization of the layout and operation allows for significant cost and energy savings. However, the accurateness of the model formulation, the practical implementation and the predicted savings have not yet been validated by experiments. For this reason, we set up a test rig which models a booster station for high-rise buildings. The test rig represents a downscaled building with five floors; and has a total height of 6 meters. 13 speed-controllable pumps are available which can be combined to a booster station in various configurations. The optimization program used in [1] is adapted to this test rig and the resulting solutions are experimentally investigated. The deviations between optimization and experimental results are analyzed and the influences of different parts of the physical model are discussed.

[1] Altherr, L.C.; Leise, P.; Pfetsch, M. E.; Schmitt, A..: Resilient Layout, Design and Operation of Energy-Efficient Water Distribution Networks for High-Rise Buildings Using MINLP. Optimization and Engineering, 2019.

■ WC-08

Wednesday, 14:00-15:40 - POT/351/H

Vehicle Routing

Stream: Logistics and Freight Transportation
Invited session
Chair: *Stefan Schaudt*

1 - Branch-and-price for the Split Delivery Vehicle Routing Problem

Kosuke Tezuka, Jun Imaizumi, Takayuki Shiina, Tetsuya Sato

Many organizations, especially transportation companies, deploy their materials or products to designated places for requirements. There are usually multiple carriers or vehicles involved in transporting tasks at the same time. Since transportation costs are often large, it is important to create an efficient schedule. However, some constraints, such as a condition that delivery vehicles have loading capacity, should be considered, and these make it difficult to determine an optimal plan. This problem is known as the vehicle routing problem (VRP) and is one of the most famous problems in mathematical programming. In ordinal VRP, the demand of a certain point or customer is satisfied by only one vehicle. On the other hand, we allow more than two vehicles to satisfy the demand of a customer and this case is formulated as a split delivery vehicle routing problem (SDVRP). SDVRP has more feasible solutions than ordinal VRP, making it more difficult to enumerate a feasible solution. Column generation is a well-known method for VRP, and we can efficiently solve SDVRP using Dantzig-Wolf Decomposition. In addition, branch-and-price, the combination of column generation and branch-and-bound, is effective for integer programming. In many cases, this method can find a better lower bound. However, the degree of improvement of the upper and lower bounds decreases with iterations, and it makes the convergence slow in the latter step of the algorithm. This results in much longer calculation time to obtain an exact solution. Because of this, branch-and-price is often used as an approximate solution method, and research on the exact solution using branch-and-price is scant. In this research, we adopt branch-and-price for the solution method and discuss the model and solution process as an exact solution method for SDVRP. In addition, we experiment and compare the results of several types of solution methods and evaluate their performance.

2 - Integrated Routing and Charge Scheduling of Electric Commercial Vehicles

Patrick Klein, Maximilian Schiffer

Increasing societal and political environmental awareness of global and local emission problems pressures the transportation sector to strive towards sustainable means of transportation. Herein, Electric Commercial Vehicles (ECVs) are considered a promising alternative to conventional vehicles as they operate (locally) emission-neutral and may reveal economic benefits that result from low operational cost. Yet, adoption of ECVs in logistics fleets is still low as some challenges, e.g. limited driving ranges and time-inefficient recharging, remain unsolved. Although these limitations have a less severe impact in city logistics, logistics service providers still struggle to realize economically worthwhile operations of electric fleets.

A major obstacle remaining in city logistics is that logistics service providers do not rely on public charging infrastructure, but charge ECVs at a central depot during off-service periods. This requires ahead of time charging schedule planning as charger availability must be guaranteed and the fleet operator aims to avoid high energy prices during early morning hours as well as increased battery degradation due to high load. Solving the resulting planning problem with a route-first schedule-second approach does not exploit the tradeoff and interdependencies between routing and scheduling decisions and their resulting costs.

Against this background, we develop the first algorithmic framework that integrates vehicle routing and charge scheduling by simultaneously optimizing vehicle tour plans and charging schedules while accounting for several real-world constraints, such as i) the non-linearity of the recharging process, ii) battery degradation caused by suboptimal charging/discharging cycles, iii) limited availability of recharging infrastructure, and iv) variable electricity costs. It comprises both heuristic and exact components including a state of the art ALNS guided by path relinking and a novel charge scheduling algorithm. We validate the algorithmic performance of both the developed matheuristic and its individual components against current state-of-the-art approaches. Additionally, we analyze the benefit of integrated tour planning and charge scheduling based on realistic instances.

3 - A Column Generation Solution Approach for the Emission-Oriented Vehicle Routing Problem with Heterogeneous Vehicles and Paths

Martin Behnke, Thomas Kirschstein

In present and future logistics, planning has to deal with the ecological effects of transportation processes. One increasingly popular topic is the reduction of greenhouse gas (GHG) emissions, which is considered as one of the major societal challenges in most developed countries. In

2016, the GHG emissions of the European Union reached the total of 4.440,8 million t CO2e. One of the most important drivers of GHG emissions is the transportation sector, which causes 24% of the total GHG emissions and is only surpassed by the GHG from energy supply (Eurostat, 2018). In the context of city logistics, there are typically a lot of different ways to travel from an origin to a destination. These alternative paths differ regarding travel speed, distance, traffic congestion, and other factors. When minimizing travel time or travel distance, usually there exists one unique shortest path connecting two nodes. In contrast, if energy (or emissions) are to be minimized, even more factors have to be considered, e.g. vehicle weight, technical vehicle specifications, as well as load weight. As a consequence, typically there exist multiple emission-optimal paths connecting an origin-destination pair which depend e.g. on vehicle type and vehicle load, see e.g. Ehmke et al. (2016) and Behnke and Kirschstein (2017). In such a setting, corresponding routing problems have to consider multigraphs, see Huang et al. (2017).

The aim of this work is to introduce a near-optimal column generation approach to solve emission-oriented vehicle routing problems on a multigraph with load-dependent and vehicle-dependent arc weights. For this purpose, the vehicle routing model is transformed into a set-covering problem (the master problem) and an elementary shortest path problem with resource constraints on a multigraph (the sub-problem). The master problem selects routes out of a set of available routes in order to serve the customer demands and minimize emissions. The sub-problem determines routes, which are feasible with respect to the routing constraints and can be used in the master problem. A backward labeling algorithm is used to solve the sub-problem. This algorithm is an extension of the algorithm by Feillet et al (2004). It is shown that the labeling algorithm can be sped up by adjusting the dual master program and by restricting the number of labels to propagate in the sub-problem. The column generation procedure is evaluated based on test instances in the Berlin city area with up to 100 customers. It turns out that the column generation approach is very effective and generates near-optimal solutions with gaps below 0.5% on average. Detailed discussions on the influence of differing parameter configurations to the runtime and solution quality as well as a comparison to the classical CPLEX approach are presented.

■ WC-09

Wednesday, 14:00-15:40 - POT/361/H

Optimization in Health Care I

Stream: Health Care Management
Invited session

Chair: *Clemens Thielen*

1 - Patient-to-Room Assignment in German Hospitals

Tabea Krabs, Christina Büsing

The assignment of patients to rooms in hospitals is a task that impacts the hospital's bed-utilization ratio as well as the provided care quality and the staff's workload. In literature, patient-to-room assignment usually focuses on finding a suitable room for every patient based on different room characteristics, while neglecting conflicts between patients or preferred pairings of patients, apart from gender separation. In German hospitals, however, these conflicts and preferred combinations of patients are the important aspect, while the rooms are all equally suitable for every patient. In this talk, we present a definition for patient-to-room assignment that was developed in cooperation with a local German hospital as well a first results on algorithms for this problem and on its complexity.

2 - The Value of Information in Flexible Nurse Scheduling

Jan Schoenfelder, Markus Seizinger

The typically high variability of demand for nursing care in individual medical units has driven many hospitals to install pools of multi-skilled flexible nurses. These nurses can be (re-)assigned to a selection of different departments on short notice, e.g. at the beginning of their shift, to assist in meeting patient demand.

An effective nurse scheduling process needs to incorporate the availability of such flexible nurses as well as patient demand information beyond the typically used single-point expected demand estimations along with workforce-related factors such as nurse availability, shift preferences, and qualifications.

We model the described problem as a multi-stage stochastic problem and translate it into the deterministic equivalent formulation. We decompose the problem into a master problem and a set of subproblems according to Dantzig-Wolfe to cope with the size of the resulting MIP. A multifactorial numerical experiment with data from our practice partner allows us to tackle the following research questions: How much improvement can be gained from the proposed scheduling process over traditional scheduling, and how does the improvement depend on the included level of demand information? What is the relationship between the size of the float pool and the resulting cost, patient care, and nurse-experience-related performance measures?

3 - A Two-Stage Formulation for the Strategic Resident Scheduling Problem

Sebastian Kraul, Jens Brunner

We present a new model for constructing strategic schedules for medical residents based on the regulations of a German teaching hospital as well as the program restrictions of the German Medical Association. In most European countries residents need to perform different interventions several times to become a specialist. These task-related programs lead to higher uncertainty in planning, so that hospital management is interested in stable rotation schedules ensuring the minimum requirements in interventions. This study will focus on Germany since there was a new release of the resident programs by the German Medical Association. Therefore, we present a new formulation of a strategic resident scheduling problem. The problem is formulated as a two-stage problem. In the first stage, we decide which rotation schedule is used for each resident, while the second stage variables represent a weekly assignment of residents to departments depending on a stochastic demand. In a computational study, we analyze the risk and effect of limiting the maximum number of rotation schedules for all residents. We evaluate our new formulation with real-world data of a German training hospital.

4 - Optimization of Duty Rosters for Physicians: A Web-Based System and its Application in Two German Hospitals

Clemens Thielen, Florian Schuler

Duty rostering for nurses and physicians is an important task within personnel planning in hospitals and has a large impact both on the efficient operation of the hospital and on employee satisfaction. Good rosters should not only satisfy many complex constraints resulting, e.g., from minimum rest times or required staffing levels, but at the same time achieve a fair distribution of the workload and adhere to the preferences of the planned personnel.

This talk presents a web-based duty rostering system for physicians that is currently being implemented in practice in two different departments (orthopedics and internal medicine) of two German hospitals. The system consists of custom-built integer-programming-based optimization models for duty roster generation and a web interface that is used to collect all necessary input data such as each physician's preferences concerning each possible duty assignment on each day of the planning period. Besides the structure of the duty rostering problems faced in the two departments, we present how fairness and physician preferences are incorporated in the optimization models used for duty roster generation and we demonstrate how the physicians' preferences are elicited via the web interface. Moreover, we present and compare two approaches for dealing with unpredictable disruptions of the generated duty rosters (caused, e.g., by absence of physicians due to illness).

■ WC-10

Wednesday, 14:00-15:40 - ZEU/114/H

Production Control and Scheduling

Stream: Production and Operations Management
Invited session

Chair: *Danja R. Sonntag*

1 - Robust optimization-based order release in engineer-to-order systems - a rolling horizon approach

Jana Plitt, Ralf Gössinger

Engineer-to-order systems are characterized by a high uncertainty in contrast to other production systems because of incomplete information about the order specification at the order arrival. Hence, two kinds of uncertainty are induced: the period of complete specification of a component (specification uncertainty) and the manufacturing process of a component (capacity requirement uncertainty). Order release initializes the execution of already accepted orders. To decide on the release of an order with incomplete specification, the order can be divided into components such that completely specified components can be released finally and components with missing specification details can be planned for release provisionally. For these components, more information is provided at a later, unknown point in time. Since information increases regarding the specification of already known orders and the arrival of new orders occur over time, we propose a rolling horizon approach that allows for considering successive information updates. In the intended paper we propose a basic optimization-based model (MILP) in order to release orders with the aim of minimizing the inventory holding, backorder and processing costs of all orders. The model is embedded in a rolling horizon such that components can be regarded dependent on their status (incompletely specified, completely specified, released, finished). Uncertainties concerning specification period and manufacturing processes (=capacity requirements) of a component are considered with chance-constrained estimations. This kind of estimation requires the setting of probability threshold parameters which have an impact on both, costs and robustness of optimal solutions. In order to inquire the model behavior in terms of costs, robustness and solution time, a numerical study is conducted. On the basis of statistical analyses, the impact of parameter settings and intervals of favorable ones are revealed.

2 - Retailer Grouping in a One Warehouse Multiple Retailer System with Time based Shipment Consolidation

Danja R. Sonntag, Gudrun Kiesmuller

We consider a single warehouse multiple retailer distribution inventory system where all retailers have to satisfy stochastic customer demands for a single product. To reduce transportation costs deliveries from the central warehouse to groups of retailers are consolidated using capacitated vehicles and 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 required safety stock. In existing literature the grouping of retailers is often given based on geographical locations. We show that a location based grouping is not suitable under stochastic demands and capacitated vehicles. Our aim is to determine the retailer groups, the corresponding routing within each group as well as the shipment intervals and the required amount of safety stock for each retailer to minimize the total average cost per period. While minimizing the costs given service level requirements at the retailers have to be satisfied and the capacity of the vehicles must not be exceeded. As the problem is an extension of the deterministic capacitated clustering problem which is already NP-hard, we present a heuristic procedure which is able to incorporate grouping, routing and inventory decisions under stochastic demands and capacitated vehicles. The results of the heuristic are compared with a location based k-means algorithm and show that costs can be significantly reduced if stochastic demands are considered while allocating retailers to retailer groups.

■ WC-11

Wednesday, 14:00-15:40 - ZEU/118/H

Project Scheduling

Stream: Project Management and Scheduling
Invited session

Chair: *Julia Rieck*

1 - A Heuristic Approach for the Multi-Project Scheduling Problem with Resource Transition Constraints

Tobias Fischer, Sebastian Velten, Markus Berg

A resource transition constraint models sequence dependent setup times and costs between activities on the same resource. The amount of setup time and costs of an activity depends on the type of the preceding activity in the sequence on the resource. The applications of such constraints are abundant, e.g., in manufacturing processes with cleaning, painting or printing operations.

In this talk, we propose a heuristic for the multi-project planning problem with resource transition constraints (MPSPT). The objective is to minimize the delay and earliness of the processes, while at the same time reducing setup costs and improving the resource utilization.

The proposed algorithm consists in three steps: The first step is to find a practicable initial solution using a constructive heuristic. The heuristic relies on priority rules that include the goals of the objective functions. Starting from the initial solution, we apply a local search in the second step of our algorithm, where we try to improve the setup costs by permuting the activity sequences on the setup resources. Finally, in the third step, we refine the solution calculated in the previous steps by a forward/backward improvement heuristic. The goal is to bring the activities closer to the due dates of the corresponding processes, while keeping the sequence of activities on the setup resources largely unchanged.

In a computational study, we demonstrate the effectiveness of an implementation based on the presented concepts using instances from practice.

2 - Project Scheduling with scarce Resources in Disaster Management

Niels-Fabian Baur, Julia Rieck

Even in highly developed countries in Europe, several disasters occur every year for which appropriate response must be planned and implemented. Since not all disasters can be prevented, the development of models and decision support systems can lead to a reduction of material damages and personal injury. Experiences show that there is usually a great willingness to voluntarily help in emergency and post-disaster situations. The volunteers with their specific skills can constitute important resources for disaster response when carrying out individual projects. They should therefore be used efficiently to exploit the potential and minimize the overall damage. 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. Each activity requires one or a combination of skills. In what follows, we understand the workforce scheduling in case of a disaster as a project and present a dynamic problem with scarce resources, time constraints and variable activity durations for, where activity durations depend on the number of resources assigned to the activity and the corresponding skill level. In order to respond to the dynamic development of a disaster, it is possible to interrupt activities and to reassign volunteers. 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.

■ WC-12

Wednesday, 14:00-15:40 - ZEU/146/Z

Practice

Stream: Optimization under Uncertainty
Invited session

Chair: *Pavlo Glushko*

1 - Examination and application of aircraft reliability in flight scheduling and tail assignment

Martin Lindner, Hartmut Fricke

This paper contributes to the research question of how new information from the digital twin of an aircraft can be used to improve tail assignment and the robustness of the flight schedules against delays. The allocation of flights to aircraft is usually a stringent process of separate planning steps with a progressive granulation through assigning flights to aircraft types, planning rotations and assigning a unique aircraft to them in the tail assignment (from 4 months up to two weeks before the flight event). However, this division into individual interim solutions leads on the one hand to only local optima, but on the other hand and especially for the tactical planning phase, it is only possible to respond purely reactionary to short-term disturbances. Thus, flight delays in daily airline operations or a failure of an aircraft can only be responded with limited flight schedule adjustments. With the

emerging technology of the digital twin (e.g. Aviatar, Lufthansa Technik), which is a virtual representation of a physically real aircraft and its technical systems, information and even predictions on the condition of the aircraft itself have recently become available. Among other things, this makes it possible to forecast the probability of a technical failure of the aircraft (Aircraft on Ground, AOG) for the scheduling time horizon. In this paper, it is examined whether and to which extent the technical availability of an aircraft could be used for robustness against disturbances in the combinatorial problem of aircraft resource planning. In a first step, the significance of such an AOG is fundamentally compared to other flight schedule disturbances (e.g. weather, missed airport slot) in terms of their effects as flight cancellation, delay, and passenger compensation costs. Afterwards, a tail assignment model that was formulated as a linear optimization problem in earlier studies is extended by the probabilistic scheduling component "aircraft reliability". Therefore, the probability for the occurrence of an AOG, assumed by a digital twin replica, as well as the resulting damage due flight cancellations are translated into a risk value, which influences as another criterion the decision making in the tail assignment. The objective function, which conventionally minimizes direct operating costs, is then extended to include such cost risks, in order to generate flight schedules in such a way that the possible damage caused by an AOG could also be reduced or minimized. Finally, the evaluation of the flight schedule is based on scenarios, where several simulated AOG cases occur at variable points of time within the planning horizon of the tail assignment. For this purpose, AOG cases which were originally classified as unlikely are also taken into account. Hereby the new flight schedule is compared with the conventionally optimized flight schedule, e.g. by costs, and a possible increased degree of robustness against AOG costs is estimated.

2 - An L-shaped method with strengthened lift-and-project cuts
Pavlo Glushko, *Csaba Fabian*, *Achim Koberstein*

Lift-and-project cuts are well-known general 0-1 programming cuts which are typically deployed in branch-and-bound-type methods to solve MILP problems. In this talk, we discuss ways to use these cuts within the framework of Benders' type decomposition algorithms for solving mixed integer two-stage stochastic programming problems with binary first-stage variables and continuous recourse. In particular, we show how L&P cuts derived for the master problem can be strengthened by utilizing second-stage information. We present an adapted L-shaped algorithm and analyse its convergence for different problem instances and values of parameters. We show, that the strengthened L&P-cuts have the potential to significantly improve the convergence of the lower bound and reduce the number of major iterations.

■ WC-13

Wednesday, 14:00-15:40 - ZEU/147/Z

Applications of Networks

Stream: Graphs and Networks
Invited session
Chair: *Bernard Fortz*

1 - Power potential, power and dominance in social networks - an entropy-driven approach
Andreas Dellnitz

Since the 1980s, scientists study the distribution of power in social networks - mostly via conducting experiments on exchange flows in networks. The results of such experiments then allow drawing conclusions about the bargaining power of actors and, hence, give an indication of their power potential. Studying respective results one might get the impression that the distribution of power in social networks is closely related to all actors' structural positions. Classical social network theory provides indices (degree centrality, betweenness centrality etc.) to evaluate the structural position of actors. However, such indices are either not in line with experimental findings or have technical issues, i.e. pre-specification of parameters. Therefore, first, we present an entropy-driven approach, which is based on a probabilistic conditional-logical framework, to determine the power potential of actors based on their structural positions - without the aforementioned shortcomings. Second, we show how to create a specific type of dominating set, using only the entropy-based power potential of actors; we call this type of dominating set a 'power dominance network'. Numerical examples demonstrate the gist of the new method.

2 - Influence maximization with competition in social networks
Michael Kahr, *Markus Leitner*, *Mario Ruthmair*, *Markus Sinnl*

We study influence maximization in social networks under competition. In the considered problem setting an entity tries to maximize its influence as a best response to a given set of (seed) nodes influenced by a competitor. Two propagation processes that occur in a discrete time setting are triggered by the two disjoint sets of seed nodes (one set for each involved entity). Influence propagation to further nodes is based on the well-known independent cascade model (i.e., based on a given probability distribution). We assume that each node can be influenced by at most one of the two entities, i.e., by the one whose influence reaches a node first where ties are broken in favor of the competitor. Since the competitors seed set is fixed in our setting, the objective of the entity is to identify a seed set (of given cardinality) that maximizes the expected number of influenced nodes triggered by that seed set. Unlike the majority of the related literature that focusses on heuristic methods, we aim for solving problem instances to proven optimality using formulations and methods based on (stochastic) integer linear programming techniques.

3 - Dynamic Adaptive Discretization Techniques for the Pooling Problem
Sascha Kuhnke, *Akshay Gupte*, *Arie Koster*

We consider the pooling problem which has important applications in industries such as refinery processes in the petroleum industry, wastewater treatment or gas transportation planning. In the pooling problem, a flow network is given which consists of inputs along with concentrations of certain specifications, pools where the flow can be mixed, and outputs along with lower and upper bounds for these specifications. Flow can be sent from inputs either directly or via pools to outputs. The objective is to minimize a linear cost function over the flow on each arc while keeping the specification values at each output between their lower and upper bounds. Due to many bilinear specification requirement constraints, this problem is a nonconvex quadratically constrained program (QCP) where nonlinear solvers have difficulties to find feasible solutions for real world instances.

In this talk, we present an iterative algorithm based on discretization to calculate high quality solutions for the pooling problem in reasonable running time. In each iteration, we solve a restriction of the original problem where we discretize the flows incident to each pool. This restriction of the pooling problem can be modeled as a mixed integer linear program (MILP) which is likely to be easier to solve than the original problem. To get more suitable discretizations, we iteratively adapt the discretization size along with the discretization values for each pool based on the previous MILP solution.

An extensive computational study on 70 medium- to large-scale test instances shows the effectiveness of this approach compared to nonlinear solvers as well as to other non-iterative discretization algorithms.

4 - New models and preprocessing techniques for segment routing optimization
Bernard Fortz

Segment routing is a modern variant of source routing in computer networks, which is being developed within the SPRING and IPv6 working groups of the IETF. In a segment routed network, an ingress node may prepend a header to packets that contain a list of segments, which are instructions that are executed on subsequent nodes in the network. These instructions may be forwarding instructions, such as an instruction to forward a packet to a specific destination or interface.

In this talk, we present models for traffic engineering in a network implementing segment routing on top of shortest paths routing protocols. We also present some preprocessing techniques that allow to decrease significantly the size of the resulting models, and present numerical experiments validating the approach on a large set of test instances.

■ WC-14

Wednesday, 14:00-15:40 - ZEU/148/U

Networks and Equilibria

Stream: Game Theory and Experimental Economics
Invited session
Chair: *Alexander Skopalik*

1 - Convergence and Hardness of Strategic Schelling Segregation

Louise Molitor

Residential areas tend to segregate over time along racial/ethnical, religious or socio-economic lines. To demonstrate that this can happen even with very tolerant residents, Schelling introduced a simple toy model which has become influential in sociology. In Schelling's model two types of agents are placed on a grid and an agent is content with her location if the fraction of her neighbors on the grid which have the same type as her is above , for some $0 < < 1$. Discontent agents simply swap their location with a randomly chosen other discontent agent or they jump to a random empty cell. Simulations of this process typically reveal that the society of agents segregates into a few homogeneous regions even for < 0.5 , i.e., when all agents are tolerant. Despite the popularity of Schelling's model, many core questions about its algorithmic properties are still open. We map the boundary of when the iterated improving responses algorithm (IIR), which is the natural algorithm for finding equilibrium states, is guaranteed to convergence. Thus we partially answer the algorithmic question of how to find equilibrium states. For this we prove several sharp threshold results where guaranteed convergence of the IIR suddenly turns into the strongest possible non-convergence result: a violation of weak acyclicity, which means the existence of states in the game such that no sequence of improving responses can lead to an equilibrium. In particular, we show such threshold results also for Schelling's original model, which is in contrast to the standard assumption in many empirical papers. We also show that in case of convergence, the IIR finds an equilibrium in O(m) steps, where m is the number of edges in the underlying graph. Moreover, we show that this bound is met in empirical simulations starting from random initial agent placements.

On the conceptual side, we investigate generalizations of Schelling's model for more than two agent types and we allow more general underlying graphs modeling the residential area. We show that the number of agent types and the topology of the underlying graph heavily influence the dynamic properties and the tractability of finding an optimum agent placement.

Authors: Hagen Echzell, Tobias Friedrich, Pascal Lenzner, Louise Molitor, Marcus Pappik, Friedrich Schöne, Fabian Sommer and David Stangl

2 - PoA for k-uniform congestion games

Walter Kern

We consider the atomic version of congestion games with affine cost functions, and analyze the quality of worst case Nash equilibria when the strategy spaces of the players are the set of bases of a k-uniform matroid. In this setting, for some parameter k, each player is to choose k out of a finite set of resources, and the cost of a player for choosing a resource depends affine linearly on the number of players choosing the same resource. Earlier work shows that the price of anarchy for this class of games is larger than 1.34 but at most 2.15. We determine a tight bound on the asymptotic price of anarchy equal to 1.35188. Here, asymptotic refers to the fact that the bound holds for all instances with sufficiently many players. In particular, the asymptotic price of anarchy is bounded away from 4 / 3. Our analysis also yields an upper bound on the price of anarchy

3 - Selfish Creation of Social Networks

Anna Melnichenko

Understanding real-world networks is a core research endeavor within the last two decades. Network Creation Games are a promising approach for this from a game-theoretic perspective. In these games, selfish agents corresponding to nodes in a network strategically decide which links to form to optimize their centrality. Many versions have been introduced and analyzed, but none of them fits to modeling the evolution of social networks. In real-world social networks connections are often established by recommendation from common acquaintances or by a chain of such recommendations. Thus establishing and maintaining a contact to a friend of a friend is easier than connecting to complete strangers. This explains the high clustering in real-world social networks. We propose and analyze a network creation model where the cost of an edge is proportional to the distance of the endpoints before establishing the connection. For this model, we provide results on the computational hardness, the game dynamics and on the existence, the structure and the quality of equilibrium networks. Our results, in particular a constant diameter and a high clustering coefficient of equilibrium networks, show that our model deserves attention as its equilibria closely satisfy real-world network characteristics.

Authors: Davide Bilò, Pascal Lenzner, Stefanie Lowski, Anna Melnichenko

4 - Nash equilibria in a Downsian competition with costs

Mark Van Lokeren

We consider a model of spatial competition where firms are competing to sell a product to customers in a given market. The market is represented by a convex set and customers are continuously distributed throughout the market according to a density function which is strictly positive. Each firm seeks to maximise its market share by choosing an optimal location in the market. Downsian competition between the firms is modelled as a non-cooperative game with the convex set as the common strategy set. However, if a firm changes its location, it incurs a cost. We determine the existence and the value of the Nash equilibrium strategies of the firms. We give examples from both the one-dimensional case (where the market is the unit interval) and the two-dimensional case (where the market is the unit square).

■ WC-15

Wednesday, 14:00-15:40 - ZEU/160/H

Real-World Applications of Location and Assignment Problems

Stream: Discrete and Integer Optimization
Invited session
Chair: *Arne Schulz*

1 - Algorithm to compute an upper bound for the competitive facility location problem with prescribed choice of suppliers

Andrey Melnikov, *Vladimir Beresnev*

We consider the competitive facility location problem with the prescribed choice of supplier. The problem can be formalized as a pessimistic bi-level program. It is relative to a family of competitive location models built on the basis of the Stackelberg game, where both the upper and the lower level problems are facility location problems with orders. For the problem under consideration, we suggest the approach to compute an upper bound for values taken by the objective function on subsets of a feasible region. The method consists in constructing estimating problems in a form of MIP obtained from a high-point relaxation (HPP) of the bi-level program. To improve the quality of the upper bound, we introduce a new family of additional constraints satisfied by any pessimistic feasible solution and reducing a feasible region of the HPP. Additionally, we describe a new procedure to generate these constraints allowing to cut-off an optimal solution of the estimating problem when it is infeasible in a bi-level sense. The procedure relies on an auxiliary optimization problem aiming to generate cuts which are as strong as possible.

2 - Optimized Resource Allocation and Task Offload Orchestration for SLA-Aware Service-Oriented Networks

Betül Ahat, *Necati Aras*, *I. Kuban Altinel*

Nowadays, mobile communication industry is subject to rapid evolution and innovations on mobile networking technologies. Smart devices and wearable gadgets have become an essential part of our lives and there is an increasing demand for services with varying characteristics and requirements. In addition, novel application areas such as Industry 4.0, machine-to-machine (M2M) communication, or smart grid are expected to be active concurrently on the same network. Although mobile devices are getting more powerful, they are still facing many challenges, and thus these service requests should be offloaded to a remote machine. Since such services are mostly latency-intolerant, optimal allocation of computation and network resources, and task assignment is crucial to handle the service requests generated by the end-users. In this study, we consider a multi-level architecture that consists of different types of computational resources and services with various characteristics and requirements. The objective is to find an SLA-aware optimal resource allocation and task assignment model for service-oriented networks. When service requests share the same resource, it causes traffic congestion on the network and an increase in the end-to-end delay in a nonlinear fashion. In order to address the latency requirements of the services, a queuing delay formulation is utilized. The resulting mixed-integer nonlinear programming (MINLP) model aims to maximize the number of successfully handled requests, and finds a destination server along with a path from user location to

destination server if the assignment satisfies the latency requirements. Our computational results for different topology sizes and load conditions show that our solution approach is able to find an efficient resource allocation and task offloading scheme while service quality is maintained above a predefined level.

3 - A balanced assignment problem
Arne Schulz

In this study, we investigate the assignment of items with different attributes to balanced groups, such that each group contains the same number of items and all pairs of groups are as homogeneous as possible with respect to the attribute values of the assigned items. This simple combinatorial problem lies at the heart of several practical applications, such as the assignment of students to groups, projects or courses. We develop a new linear objective, which weights deviations between groups with respect to their size and study the effects of assigning items via a restricted block property. We present experimental results along with a comprehensive complexity analysis.

■ WC-16

Wednesday, 14:00-15:40 - ZEU/250/Z

Analytics for Time Series Data

Stream: Business Analytics, Artificial Intelligence and Forecasting
Invited session
Chair: *Kei Takahashi*

1 - Simple Method for Unsupervised Anomaly Detection: An Application to Web Time Series Data
Keisuke Yoshihara, Kei Takahashi

We propose an anomaly detection method that is applicable to unlabeled time series data utilizing the density ratio estimation based on the state space model. In recent years, more business entities are relevant to advertising because of the shift from conventional mass media advertising to digital advertising, which is associated with the emergence of new technology-driven advertising. In terms of the advertising on an electronic commerce (EC) sites, not only the physical (traditional) advertising agency but also the web advertising agency, the EC sites' owner, production and management firms are involved. Under such circumstances, the information among relevant business entities is more likely to be asymmetric. For example, the unexpected events are possible for web advertising agency such as sudden increase in the number of visitors to EC site caused by spot TV commercial. Such events look like outliers on unlabeled time series data from a web advertising agency's point of view. Detecting outliers and pinning down the source of them are especially important for less informative entities. In the paper, we propose a simple anomaly detection method that is enough tractable even for non-technical entities. Our detection rule is based on the likelihood ratio estimated by dynamic linear model, i.e. the ratio of likelihood of our model to that of an over-dispersed model that we call NULL model. The idea is that an observation must be an outlier if the likelihood of NULL model is greater than that of our model since outliers arise in tail of the distribution of our model and the probabilities of arising such observations are expected to be higher for over-dispersed NULL model. We apply our method to daily page view data on EC site dealing in insurance goods from 2015 to 2018 and show that it is sufficiently applicable to real-world data by finding out that the outliers in our data are caused by delivering e-mail newsletters.

2 - Multivariate extrapolation - a tensor-based approach
Josef Schosser

This paper deals with the relationship between two streams of literature (or, "cultures"), temporal link prediction on the one hand, and time series analysis on the other hand. These cultures have a lot in common. Among others, they are longitudinally oriented and seek for automatic procedures which can be applied in a push button fashion. However, there are also clear differences. Link prediction can be found within the field of computer science, whereas time series analysis is closely connected with the fields of statistics and operations research. Within time series analysis, single time series are assumed to be independent. In contrast, relational data violates assumptions of independence and link prediction takes care of (dynamic) inter-relationships. Moreover, temporal link prediction mostly deals with binary data or ordinal data. In the context of time series analysis, one often encounters count data. Recently, tensor extrapolation tries to integrate temporal link prediction and time series analysis with the help of multi-linear algebra. Tensors (or, multi-dimensional arrays) are central to multi-linear algebra. They allow for extracting and exploring the properties of multi-way data. In particular, tensor decompositions are able to extract meaningful, latent structure in the data. Within the approaches to tensor extrapolation, tensor decompositions are used to identify periodic patterns in the data, which then serve as input for time series methods. However, existing literature on tensor extrapolation is restricted to special cases and typical applications of link prediction.

The paper at hand contributes to the literature in the following way. First, it connects state-of-the-art tensor decompositions with a general class of state-space models underlying exponential smoothing. In doing so, it offers a useful framework to summarize existing literature and provide various extensions to it. Second, it goes beyond the boundaries of traditional link prediction and investigates the conditions for use in typical fields of time series analysis. Through several numerical experiments, it demonstrates the effectiveness of the proposed method. It synthesizes data that exhibits different periodic patterns and shows that the approach is able to reveal these patterns in time. Moreover, it uses real-world data to demonstrate the superiority of the method over traditional extrapolation approaches. The latter cannot capture dynamic inter-relationships between variables of interest. In contrast, the proposed method identifies these associations and significantly improves forecast accuracy. That means, accounting for the relational character of the data pays off.

3 - Predicting prices of electric components in the B2B market
Kei Takahashi

This study proposes a new method for price prediction of electric components in the B2B market. The B2B market of electric components is characterized by difficulty of product differentiation. Then the market tends to be under price competition. Therefore, precise price prediction is important for electric component makers. This study introduces Independently Interpretable Lasso (IILASSO) to predict future prices of electric components with time series data. The data are deal transactions including customer ID, customer group ID, features of product, quantity, and unit price. In the B2B market of electric components, there are plural prices in the same electric component because of difference of purchasing power in each customer, local unbalance in supply and demand, and fluctuation of foreign exchange rate. Price trends of electric components are strictly downward, but there also exists differences of trend in the same electric component. Therefore, we develop a multi-level regression model with future selection. In this modeling, there are two problems to overcome. Firstly, we collapse not angles in the multi-level to zero but differences of angles in the multi-levels to zero. To overcome this problem, we introduce pre-analysis with ordinary regression and modification of data to reflect angle similarity. Second problem is selection of correlated variables with sparse regularization. Performance of sparse regularization such as Lasso is guaranteed only under small correlation assumption. However, in multi-level settings under strictly downward situation, time series data are highly correlated. This paper introduces IILASSO to bridge this problem. IILASSO has penalty components that reflects similarity between variables automatically. The model is applied to actual data in the electric components' maker. As a result of this empirical analysis, we achieve more precise prediction with IILASSO than that with LASSO and ordinary regressions.

■ WC-17

Wednesday, 14:00-15:40 - ZEU/255/Z

Multi Objective Optimization

Stream: Decision Theory and Multiple Criteria Decision Making
Invited session
Chair: *Jutta Geldermann*

1 - Multiobjective Optimization Under Uncertainty: A Robust Regret Approach
Patrick Groetzner, Ralf Werner

Consider a multiobjective decision problem with uncertainty given as a set of scenarios. In the single criteria case, robust optimization methodology helps to identify solutions which remain feasible and of good quality for all possible scenarios. Here one method is to compare the possible decisions under uncertainty against the optimal decision with the benefit of hindsight, i.e. to minimize the regret of not having chosen the optimal decision. In this talk, I will extend this regret to the multiobjective setting to introduce a robust strategy for multiobjective optimization under uncertainty.

2 - Decision-making for project realization/support - approach based on stochastic dominance rules versus multi-actor multi-criteria analysis
Dorota Górecka

The selection of projects for realization or co-financing is a complex process, often strategic in nature, which involves confronting trade-offs between multiple, frequently conflicting, factors. In this process the expectations of various stakeholders should be taken into account, while simultaneously ensuring the achievement of numerous objectives: economic, technological, social, and environmental, as well as objectives connected with public relations and safety. It is therefore necessary to use structured, explicit approaches and carry out a thorough analysis of the advantages and disadvantages of individual projects from the point of view of many criteria, taking into consideration different, or even conflicting, priorities of decision-makers in order to make a decent, informed decision: to select good projects that will be implemented, and to reject bad projects - unreal, unprofitable, unhelpful, unattractive. The aim of this work is to compare the application of two multi-criteria decision aiding (MCDA) approaches that can be employed to solving the problem of project selection: outranking methods for mixed evaluations (stochastic and deterministic ones), namely BIPOLAR MIX and the EVAMIX method for mixed data, and multi-actor multi-criteria analysis (MAMCA). The problem is illustrated by the case of ranking environmental infrastructure projects.

3 - Cultural destination selection by utilizing DEMATEL and VIKOR methods.
Erdem Aksakal, Emre Çalışkan

Tourism has become one of the fastest growing sectors all over the world under the continued economic growth and creating value. The tourists decide to visit an area within the countries culture, traditions, heritage, nature and etc. The reasons that make tourism to create value is the cultural side of the countries. Because cultural tourism depends both on the natural and cultural resources of the countries. In practically, tourist satisfaction for selection process can be affected for many reasons. But for cultural tourism, the reasons can be evaluated within a limited context through the tendency of the tourists. The main idea of cultural tourism is to visit historic sites or participating in historic activities. For the determined appropriate destination problem, the criteria were selected from the "The Travel & Tourism Competitiveness Report 2017" of the World Economic Forum. The countries identified from World Travel Awards data. The decision process consists of six criteria and nine countries. In this study, an evaluation model is designed to select a suitable cultural destination for travelers from TURKEY. The model uses DEMATEL and VIKOR methods together. DEMATEL method is used for determining the weights of the criteria determined for selection and VIKOR method is used for the selection process.

■ WC-18

Wednesday, 14:00-15:40 - ZEU/260/H

Supply Chain Management

Stream: Supply Chain Management
Invited session
Chair: *Marjolein Buisman*

1 - Maximizing the window fill rate by allocating spares in a periodic review inventory system
Michael Dreyfuss, Yahel Giat

We study the spares allocation problem in a multiple-item, multiple-location inventory system with periodic review. The system allocates spares with the objective of maximizing the window fill rate, which is the probability that a random customer is served within a given time window. The advantage of the window fill rate as a service performance measure is that it takes into account that customers may tolerate a certain wait before they are served. We develop the window fill rate formula and show that, depending on the tolerable wait, it is either a constant, concave or convex-concave with the number of spares. We use this result to develop an efficient algorithm to find the optimal spares allocation for a given budget or for a given target window fill rate. We show that when the tolerable wait or the budget are small, spares will be clustered in a subgroup of the locations (or item-types), while the other locations (or item-types) do not receive any spares. In addition, we numerically illustrate the spares allocation problem using two different synthetic large-scale examples. In particular, we use these examples to demonstrate the additional spares needed due to the periodic review compared with a continuous review. The numerical illustration also highlights the complexity of the window fill rate and the savings gained by using it as an optimality criterion.

2 - On Modeling the Single Period Spare Parts Distribution System Design Problem by Mixed Integer Linear Optimization
F. Tevhide Altekin, Abdullah Dasci, Hazal Ercan, Guvenc Sahin, Ajinkya Tanksale

In this paper, we develop and solve mathematical models for the single period spare parts distribution system design problem. The multi-echelon spare parts distribution system consists of one distribution center, several warehouse locations and a sizable number of authorized repair vendors that must be supplied a number of different parts. The corresponding system design problem involves determining the warehouse locations, sizes of the inbound vehicles to the opened warehouses, sizes of the outbound vehicles and the routes to the repair vendors so as to meet their demands for different parts while minimizing the total cost. The inbound and outbound transportation costs are represented by staircase cost functions so as to model different vehicle sizes. We assume a large number of heuristically generated routes are given and a repair vendor is allowed be served by more than one route and/or warehouse. A mixed integer programming formulation of the problem is provided. As problems involving staircase costs are known to be quite challenging due to the weak lower bounds, we explore different approaches to strengthen the proposed formulation. The effectiveness and efficiency of the proposed approaches are studied through computational experiments.

3 - Design of distribution systems in grocery retailing
Andreas Holzapfel, Heinrich Kuhn, Tobias Potoczki

We examine a retail distribution network design problem that considers the strategic decision of determining the number of distribution centers (DC), their type (i.e., central, regional, local), location and store assignments, and anticipates the tactical decision of allocating products to different types of DC. The resulting distribution structure is typical for grocery retailers that choose to operate several types of DC storing a distinct set of products each. We propose a novel model and sophisticated solution approach considering the decision relevant costs along the retail supply chain.

4 - Financial and Environmental Effects of Closing the Loop in Supply Chains
Mehmet Alegoz, Onur Kaya, Z. Pelin Bayindir

Over the past years, closed-loop supply chains gained a considerable attention in both academia and industry due to environmental regulations and concerns about sustainability. Although it is addressed by many researchers, not much attention is given to the effects of closing the loop in supply chains. By this context, in this study, we focus on the financial and environmental effects of closing the loop in supply chains in an environment where demand, return rate and returned product quality are uncertain and we propose a set of two stage stochastic programming models for both forward and closed-loop supply chains to see the effects of closing the loop in supply chains. We make various sensitivity analysis to see the effects of parameters. We also study three well-known and widely used emission policies; carbon cap, carbon cap-and-trade and carbon tax together with the case of no emission regulation and compare the forward and closed-loop supply chains under these policies. Computational results allow us to obtain important insights regarding the percentage cost difference and emission difference between forward and closed-loop supply chains in different problem settings.

5 - The reduction or re-use of food waste at the retailer
Marjolein Buisman, René Haijema, Jacqueline Bloemhof

Up to one third of the food produced is wasted along the food supply chain; of which 5% at the retail. The retail has a key role in the food chain as many different supply chains come together. Moreover, it is the last stage at the supply chain where logistical interventions can be implemented to tackle the food waste problem. In this research, we address the food waste at the retailer, and propose several interventions to reduce the waste levels, or to re-use the leftovers. Four interventions are studied: (i) applying a discount on nearly expired products, (ii) the use of a dynamic shelf life, (iii) the incorporation of consumer driven substitution within the replenishment and assortment decisions and (iv) the re-use of leftover food at a soup kitchen. Besides affecting the food waste levels at the retailer, these interventions also affect profit and service levels. The first and second intervention, a discount and a dynamic shelf life are studied with a simulation-based optimization model. For a highly perishable product, the replenishment levels are optimized. Applying a discount reduces food waste due to the price sensitive consumers, which switch from purchasing the freshest product to the discounted 'older' product. The use of a dynamic shelf life has a great potential to reduce food waste, without a loss of profit. Moreover, the waste reduction improves the service level. Inclusion of substitution in the replenishment and assortment decisions is studied for two highly perishable products. The replenishment decision of the two products is combined, under one-way substitution in the case of a stock-out. For high substitution fractions, it can be optimal to only have on product in stock, where for lower substitution fractions both products should be kept in stock. The reduction of food waste can be substantial when the replenishment decisions of the products are combined. Moreover, profit levels increase. Overall service levels increase, however for individual products, the service level might decrease. The two-product case is extended to a multi-product problem, with two-way substitution and multiple substitution rounds. To solve this problem, an algorithm is proposed which provides (near) optimal solutions. This study shows the importance of including the multiple substitution rounds. Moreover, it considers both assortment and inventory decisions, which changes the optimal solution, compared to pure assortment planning. Food waste can never be reduced completely; therefore the last intervention studied is the re-use of food leftovers. A menu-planning model is developed for a soup kitchen, which uses food leftovers donated by retail. Under meal variety constraints, the model provides a meal plan with minimal costs for the soup kitchen. Results show that by optimization, most leftovers can be used efficiently. This contribution is based on the final results of a PhD thesis part of the EU-Horzion 2020 project REFRESH.

Wednesday, 16:10-17:25

■ WD-01

Wednesday, 16:10-17:25 - POT/006/H

Workforce Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Sophie Parragh*

1 - A Decomposition Heuristic for Rotational Workforce Scheduling
Tristan Becker

In rotational workforce planning, a schedule is created from a sequence of work and rest periods. Each employee starts at a different part of the schedule and after a certain time the schedule is repeated. The duration of the schedule increases with a higher number of employees. At the same time, various constraints on work sequences and days off must be taken into account. For a large number of employees, it is difficult to create a schedule that meets all requirements. Further, due to the interactive process of shift planning, it is important to ensure low solution times regardless of the specific problem instance characteristics. Therefore, a new mathematical formulation and decomposition approach for rotational shift scheduling are proposed. The decomposition takes advantage of the fact that most of the constraints in rotational workforce planning are imposed on the work shift sequence. By considering a fixed set of shift blocks that meet the staffing requirements, the problem complexity can be greatly reduced. Then, by using a network model, it is easy to determine whether a feasible sequence of shift blocks exists. The decomposition approach is applied to the problem structure of the Rotating Workforce Scheduling Problem, but can be extended to different problem structures. In a computational study we compare the mathematical formulation and the decomposition approach with earlier exact and heuristic approaches. Computational results show that the decomposition approach outperforms the previous heuristics for every instance of the standard benchmarks. The mathematical formulation is solved with standard solvers and turns out to be competitive.

2 - A Large Neighborhood Search Algorithm for Employee Scheduling with Parallel Task Assignments
Martin Gutjahr, Sophie Parragh, Fabien Tricoire

This paper considers a real world scheduling problem in which the assignment of tasks with fixed starting times to a set of employees is regarded. Each employee may perform multiple tasks in parallel, depending on the employee's skill level. In addition, planning considers restrictions regarding shift lengths, employee availabilities and complex break scheduling. Legal requirements for breaks and rests have to be taken into account, as well as break splitting possibilities. Furthermore, the problem includes mandatory tasks and consecutivity relations. The aim is to maximize the number of assigned tasks weighted by their priorities, to minimize penalties for the assignment of tasks to underskilled workers, the assignment of different types of tasks in parallel and to maximize the amount of consecutive tasks processed by the same employee. We model the program in terms of a mixed integer program and we propose a large neighborhood search algorithm with tailored destroy and repair operators. Destroy operators are constructed to take advantage of the layout of an employee scheduling problem. Repair operators sort possible employee task assignments based on varying opportunity cost considerations. Benchmark instances used to test the algorithm are derived from real world data including over 10000 tasks, over 100 employees and time frames of up to one week.

■ WD-02

Wednesday, 16:10-17:25 - POT/051/H

Logistics Networks & Distribution

Stream: Logistics and Freight Transportation
Invited session
Chair: *Sebastian Risse*

1 - A reverse logistics system when (re)manufactured items are sold on different markets

Imre Dobos, *Grigory Pishchulov*, *Ralf Gössinger*

We study an integrated production-inventory system that manufactures new items of a particular product and receives some of the used items back after a period of use. These can be either remanufactured on the same production line or disposed of. Used items awaiting remanufacturing need to be held in stock. Both manufacturing and remanufacturing operations require setting up accordingly the production equipment. Compared to manufacturing, remanufacturing may induce a different (possibly a lower) production cost rate, while remanufactured items meet only lower quality standards and are sold on different, quality-dependent markets. New and remanufactured items are kept in stock, from which the market demands are satisfied. Controlling such a system involves decisions with regard to disposal of used items, succession of manufacturing and remanufacturing operations, and the choice of respective batch sizes. Existing research has studied control policies for such production-inventory systems in a variety of different settings. Specifically, beginning with the work of Schrady (1967) and Richter (1996), significant attention has been devoted to settings assuming deterministic constant demand and return rates. A more recent work has referred to settings assuming variation in quality of returned items (Dobos & Richter 2006) as well as a limited number of remanufacturing cycles that an item can undergo due to wear and tear (El Saadany et al. 2013). Another stream of literature considers that markets for newly manufactured, remanufactured and refurbished items are different (Jaber & El Saadany 2009; Alamri 2011) and thus returning items need to be inspected and sorted according to their reuse quality (Konstantaras et al. 2010, Dwicahyani et al. 2016). We extend these lines of research by studying a setting in which used items return in a quality condition that depends on the number of remanufacturing cycles an item has undergone and determines the inventory holding costs of that item. We seek to determine an optimal allocation of manufactured and remanufactured items between quality-dependent markets. The allocation of items between markets is based on a modified classical transportation problem. The cost function of the problem represents the revenue loss in case a product is sold on a lower quality market than it might have been. It is shown that the optimal solution approach is very similar to a simple initial heuristic for the classical transportation problem, which is the Northwest Corner Rule.

2 - Multiscale Optimization of Logistics Networks

Karl Däubel, *Frieder Smolny*, *Martin Skutella*, *Guillaume Sagnol*, *Torsten Mütze*

The strategic and tactical planning of logistics networks includes the solution of location and multicommodity flow problems with respect to nonlinear transport costs and a multitude of additional constraints. In recent years, instances arising in practice have grown rapidly in network size and in the number of demands. The research project LogiScale that we present in this talk addresses these challenges using a multiscale approach. Specifically, we develop techniques to aggregate network data, tariffs and demands in logistics networks while preserving connections to the original data in order to recover feasible solutions of good quality. We then present a generic optimization procedure that repeatedly solves coarsened versions of the original instance, dynamically adapting the granularity where it seems most promising.

In this talk, we will focus on the algorithms and data structures implemented within this project, both for a multicommodity flow problem arising in tactical planning and a facility location problem arising in strategic planning. Furthermore we discuss computational results on real-world logistics networks provided by our industry partner 4flow.

In the remainder of this extended abstract, we briefly describe the main ingredients of our approach. We modify the network by merging/splitting nearby sinks and sources. These modification operations yield an order relation (refinement or coarsening) on the set of instances to the considered problems. Hierarchical clusterings of sources and sinks of the input network yield a hierarchy of problem instances ordered by this relation as follows: The top of this hierarchy represents the original instance. The children of an instance in the hierarchy are those instances arising from merging a set of nodes (sources of sinks) that got clustered together. We keep track of this hierarchy of instances in a dynamic DAG-like data structure. This data structure allows us to modify the instance currently considered as described above by providing the necessary links to the original data.

Solutions of the considered problems can be translated between the different instances in the hierarchy by local changes. Every solution in a coarsened instance corresponds naturally to a solution in the fully refined original network. By problem specific techniques we ensure that the cost of a solution in one of these smaller instances is at most the cost of the corresponding original solution.

The final ingredient are heuristic algorithms that run after each network modification step. On the coarser levels, where the network size is small, computationally more expensive algorithmic techniques such as MIP may also be employed.

Overall, our algorithmic approach seems promising for all hard optimization problems where we can exhibit a local modification operation that does not change the global structure of good solutions too much.

3 - Integrated Automotive Production and Distribution Planning

Sebastian Risse, *Kevin Tierney*

Automotive supply chains have become increasingly complex due to the growth in both product customization and size of the underlying distribution network. State-of-the-art planning methods solve the problems of production and distribution sequentially, potentially leading to poor solutions as the two problems have conflicting objectives. The production problem aims for the highest possible factory output, whereas the distribution problem wants to reduce the lead time in its network to a minimum.

We propose a novel mathematical model for integrated automotive production and distribution planning, with the objective of determining a production schedule with high utilization and distribution plan with low lead times. The model considers the problems that arise from mass customization and their impact on production and distribution by integrating an order assignment problem with a routing problem.

We evaluate the model on real-world data from a large automotive company, showing that integrated planning leads to better planing scenarios, which come at a high computational cost. Previous works have not covered the complexity arising from mass customization and its impact on the attached processes in a fitting way for the automotive industry.

■ WD-03

Wednesday, 16:10-17:25 - POT/081/H

Intelligent and Configurable Metaheuristics

Stream: Metaheuristics
Invited session
Chair: *Kevin Tierney*

1 - A Method for Realtime gray box algorithm configuration

Dimitri Weiß, *Kevin Tierney*

A solver's performance and run time is closely linked to the settings of its parameters. Finding these parameters by hand is tedious and difficult, thus automatic algorithm configurators have been created to assist researchers and practitioners in selecting high-quality parameters. To date, algorithms configurators have taken a black box approach in which the internals of the solver being configured or intermediate output are not considered during configuration. We propose a gray-box approach in which the intermediate output of a solver, e.g., the solution quality or gap to a known bound, assist in the configuration process. We implement the gray box mechanism within a realtime algorithm configuration framework that adjusts parameters in an online setting. In this setting, instances are received one at a time and must be solved immediately, meaning parameters must be adjusted online through parallel executions of the solver, rather than offline in a batch. We compare our gray box configurator to a black box equivalent on several real-world experimental settings.

2 - 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. 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.

3 - Parameter selection and analysis in granular local search for vehicle routing problems
Jean-Bertrand Gauthier, Michael Schneider, Timo Gschwind, Christian Schroeder

Despite being quite flexible in adapting to various optimization problems, metaheuristics are subject to a variety of parameters that affect their behavior. Many state-of-the-art metaheuristics for vehicle routing problems (VRPs) use at their core a local search mechanism. Within the last decades, several variants of local search using different neighborhood structures, operators, pruning rules, and search strategies have been developed. Despite the importance of local search in metaheuristics for VRPs, no systematic investigation of the effect of its components and no design recommendations exist. By this we mean that parameter selection has certainly been studied for multiple metaheuristics in various degrees sometimes even coming down to prescribing specific values but the bigger picture as to why these values make sense is left up to the imagination. In this respect, we follow a statistical approach as many of our peers have done before us, but our intent is rather to try to identify recurring patterns in the local search behavior. This study compares the performance of a large number of granular local search variants on benchmark instances of the capacitated VRP and the multidepot VRP. We use performance profiles to visualize the results with regards to solution quality and runtime. A Wilcoxon signed-rank test is used to determine dominated algorithm variants. In this way, we are able to assess the impact of different local search components and to give design recommendations.

■ WD-04

Wednesday, 16:10-17:25 - POT/106/U

Algorithms for Nonsmooth optimization: Theory and Applications I

Stream: Control Theory and Continuous Optimization
Invited session
Chair: *Andrea Walther*

1 - Global Derivatives
Uwe Naumann, Jens Deussen

By definition, a derivative f'(x) is a local property of a differentiable function f at a given point x. Deterministic globalization of this information to cover an entire neighborhood of x is the subject of this contribution. Potential target applications include parameter sensitivity analysis, error estimation, and (global) nonlinear optimization [1]. We focus on McCormick relaxations of factorizable functions implemented as computer programs. They yield a convex hull of the function over a given subdomain. Recursive domain decomposition results in improved estimates. Both over- and underestimators turn out to be Lipschitz continuous. Subgradients can be computed by algorithmic differentiation in both tangent and adjoint modes [2]. For a given point x within the domain of f and an upper bound on the width of the interval F' overestimating f'(x) we aim to determine the largest possible dX such that f'(x+dx) lies within F' for all dx in [0,dX]. We discuss technical details of the proposed approach supported by numerical results.

[1] Deussen, Naumann: Interval adjoints in deterministic global optimization. To appear in proceedings of 6th World Congress on Global Optimization (WCGO19), Metz, France, 2019. [2] Beckers, Mosenkis, Naumann: Adjoint mode computation of subgradients for McCormick relaxations. Recent Advances in Algorithmic Differentiation, 103-113, Springer 2012.

2 - Missing Value Imputation via Nonsmooth Optimization and Clusterwise Linear Regression
Napsu Karmitsa, Sona Taheri, Adil Bagirov, Pauliina Mäkinen

A new method of preprocessing incomplete data is introduced. The method is based on clusterwise linear regression and it combines two well-known approaches for missing value imputation: linear regression and clustering. The idea is to approximate missing values using only those data points that are somewhat similar to the incomplete data point. A similar idea is used also in clustering based imputation methods. Nevertheless, here the linear regression approach is used within each cluster to accurately predict the missing values, and this is done simultaneously to clustering. The underlying clusterwise linear regression problem is modelled as a nonsmooth optimization problem and solved using nonsmooth optimization techniques combined with an incremental approach. The proposed method is tested using some synthetic and real-world data sets and compared with other algorithms for missing value imputations. Numerical results demonstrate that the proposed method produces the most accurate imputations in data sets with a clear structure and the percentages of missing data no more than 25%.

3 - T.he B.undle A.pproach – Scaling in ConicBundle 1.0 for Convex and Conic Optimization
Christoph Helmberg

In the majority of current large scale convex optimization applications, subgradient algorithms dominate today because they are easy to implement, they have low iteration complexity and yet exhibit optimal convergence rates for first order oracles. Bundle methods try to make better use of the same information by forming a cutting model from collected subgradient information and by determining the next candidate as the minimizer of the model augmented with a proximal term. While their convergence properties are much harder to analyze, the choice of cutting model and proximal term offers a lot of flexibility. Suitable choices may even allow to move towards second order behavior. After a short introduction to bundle methods in general, we discuss the current approach for integrating such choices in the forthcoming ConicBundle 1.0 for the general and the semidefinite case and report on experience gathered on several test instances.

■ WD-05

Wednesday, 16:10-17:25 - POT/112/H

New developments in railway optimization

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Christian Liebchen*

1 - Quantifying the effective residual train capacity in railway networks with predefined train services
Norman Weik, Emma Hemminki, Nils Nießen

In this paper we address a special variant of the freight train routing problem and its application in railway capacity planning. Extending previous work by Cacchiani et al., Trans. Res. B (2010), we consider the routing of extra trains within an existing timetable according to the residual network capacity.

A two-step routing approach based on a time-expanded network is proposed: In the first step, the number of additional trains subject to an upper bound on train running time is maximized, hence quantifying residual capacity for extra trains on given network relations. In the second step, running times of trains are minimized under the constraint that all trains have to be routed.

By ensemble averaging over a random spatial and temporal distribution of residual network capacity, general bounds on the number of additional freight trains can be established regardless of the structure of the underlying (passenger) timetable. This approach is primarily suited for densely interlinked railway networks where multiple lines converge in stations and timetable structure and train sequence change significantly in stations.

The method is demonstrated in an application scenario for freight train routing in North Rhine Westphalia. In addition, the results of our method and the quality of the obtained train routes (in terms of running times) are compared to sequential train routing, hence making the advantages of simultaneous freight train routing in timetabling quantifiable.

2 - Strategic planning for autonomous on-demand rail units in rural area networks

Stephan Zieger, Christina Büsing, Martin Comis, Nils Nießen

In large parts of Europe, we observe the population being drawn to metropolitan areas. As a result, the population in the rural areas declines which in turn leads to the recent closure of several rural railway lines as regular services became unprofitable. In an attempt to revive these regional rail networks and increase the appeal of rail transportation, mobility operators discuss the implementation of Autonomous Rail Units (ARUs). ARUs are small capacity rail units that operate on-demand as opposed to regular service to allow for profitable operation in low demand environments. In order to successfully operate ARUs, decision-makers have to decide on a reasonable number of provisioned units. To aid this strategic decision, we investigate the number of units required to service a given set of requests.

As part of these investigations, we restrict the rail network in a first step to a double-track railway line and consider an offline setting without ride-sharing. Hence, requests for the following time period are known a priori and have to be assigned to individual ARUs. Each request specifies a customers' wish to be transported from an origin to a destination starting at a given time.

To determine the minimum number of ARUs such that all requests can be served without inducing waiting times, we construct an acyclic time expanded digraph containing one node for every station and every time step as well as a global source and sink. Feasible unit movements within the rail network are represented by directed arcs such that travel times are reflected by the nodes' difference in the time expansion. The global source is connected to all stations at time zero by arcs that model the introduction of a new ARUs. All stations at the end of the time horizon are connected to the global sink. Service requests are represented by a set of arcs such that given starting times are reflected by the time expansion.

By properly choosing node balances, arc costs, and arc capacities, we show that the minimum number of required ARUs can be computed via a minimum cost b-flow in the constructed graph. This yields a pseudo-polynomial algorithm for our investigated problem. Moreover, by means of flow decomposition, we obtain optimal ARU schedules including the assignment of requests to units.

Finally, we evaluate how the proposed model can help the strategic planning of online ARU operations. To that end, we transfer the decision concerning the number of ARUs as determined by our offline model into an online setting in which requests are heuristically assigned to ARUs. By means of discrete-event simulation, we obtain estimations to the system's expected utilization as well as the expected quality of service and subsequently evaluate the impact of varying the number of operating units.

3 - A Collection of Aspects Why Optimization Projects for Railway Companies Could Risk Not to Succeed - A Multi-Perspective Approach

Christian Liebchen, Hanno Schülldorf

You might be aware of the following gap: There are by far more publications on promising projects on how mathematical optimization could improve the performance of railway companies, than true success stories in the sense that operations research methods really entered the practice of railways. In this paper, we shed a bit of light on those projects, which finally did not enter the practice of railways. We do so by conducting a survey in which we ask both, railway practitioners who served as ordering party, and optimization experts who served as R&D solution provider. We summarize and comment the most frequent replies to our question about the key factors why in the past mathematical optimization methods did not enter the practice of railways: expert capacity for validation, management attention, quality of input data, and "moving target" objectives. Hereby, we offer a knowledge base to future project managers. Acting accordingly with respect to definition of project goals, project design, and project management, hopefully lets them come up with even more true success stories of operations research methods in the practice of railways. (originally presented at ICROMA 2019, aka RailNorrköping 2019)

■ WD-06

Wednesday, 16:10-17:25 - POT/151/H

Gas market and infrastructure

Stream: Energy and Environment
Invited session
Chair: *Dogan Keles*

1 - Modelling Demand Uncertainty in the European Natural Gas Market: A robust optimization approach

Matthew Schmidt

Natural gas is a key energy source in modern economies, being used for heating, electricity production as well as a combustion fuel for industrial processes. In Europe, the domestic production of natural gas is steadily decreasing coupled with an increasing trend in worldwide consumption, meaning that Europe's dependence on natural gas imports is set to rise while competition for foreign resources concurrently increases. This uncertainty is likely to present infrastructural challenges as increased transportation capacities are needed. Furthermore, due to climate targets natural gas as a feedstock for electricity and heating applications is subject to considerable uncertainty. While in the long-run a decreasing demand for natural gas is to be assumed, its use as a transition fuel to back-up renewable production could prove to bolster its demand in the near to medium term. While a variety of approaches have evaluated demand uncertainty in the European natural gas market to date, the proposed approach explores the application of robust optimization. Robust optimization, also referred to as risk-based decision-making involves the minimization of costs under the worst realization within an uncertainty set. This optimization technique can be valuable when confronted with long-term uncertainties where probability distributions are unknown, risk-averse investment is preferable or solutions exhibit strong sensitivity to minorchanges in the assumptions or data sets. For our case study, a multi-stage adaptive robust optimization is implemented on a pared-down version of the gas market model GAMAMOD with added investment, a bottom-up model used to analyze the natural gas supply structure in Europe and to examine the utilization of the natural gas infrastructure. Using a polyhedral uncertainty set for the demand, the three-level optimization problem is decomposed into a master and subproblem and is solved iteratively. A comparison with a deterministic pathway of demand growth is performed. The results provide an indication as to the necessary investment costs in infrastructure necessary to protect the network against the risk of a worst-case demand realization in the next decades.

2 - Infrastructure expansion in the European natural gas market considering uncertain gas demand

Philipp Hauser

Motivation German and European climate policies aim to reduce CO'2-emissions. Against this background, the role of gas in the energy mix and the resulted gas demand pose the question whether additional in-vestments in gas infrastructure are needed during the next decades. In gas markets, uncertainties occur in many different dimensions. Firstly on the demand side, where in the electricity sector gas power plants provide flexibility with lower emissions than lignite or coal power plants. However, gas power plants currently suffering from low electricity prices and thus the future level of gas demand in this sector is unclear. This situation might change in Germany after the nuclear phase out after 2022 and the enforced coal phase out during the 2020s and 2030s. Sec-ondly, uncertainties raise on the supply side, where decreasing European gas production in Western Europe, in particular in the Netherlands and Germany after 2030, enhance the market position of non-European suppliers as Russia or Qatar and simultaneously increase the European dependence on supplies of these countries. Thirdly, uncertainties grow on the transmission side, where Russia tries to build new transmission routes to Europe e.g. Nord Stream II and Turkish Stream. These activities change supply structures in Europe and increase European dependence on transfer countries. Finally, political interests influence supply and transmission structure in the European gas market, as for example Germany shows ambitions building a national liquefied natural gas (LNG) terminal to ena-ble LNG imports, e.g. from Australia, Qatar or USA.

Research question: According to these challenges this work will focus on uncertainties on the demand side and their impact on the supply infrastructure. As the overall goal of energy policy is to ensure security of sup-ply, the question of diversification in both, gas suppliers and transmission ways, gains in im-portance. Therefore, the objective is to calculate the value of diversified infrastructures using an

extended version of the linear optimization model Gas market model (GAMAMOD-EU).

Methodology: An application of the stochastic programming approach will be introduced in order to evaluate total system costs of different infrastructure expansion options by taken natural gas demand uncertainties into account. Finally, the results of optimal gas infrastructure will be evaluated using model simula-tion runs, where supply disruption are assumed.

Expected results: The future gas demand determines the need of gas import infrastructure. It is expected that the con-sideration of gas demand scenarios show difference in infrastructure expansion compared to deter-ministic model approaches. Simulation runs might show that considering gas demand uncertainties and a resulting diversified gas infrastructure increase gas supply security compared to non-diversified, i.e. Russian dominated, gas supply.

3 - Hybrid production networks for renewable fuels

Larissa Doré, Tristan Becker, Grit Walther

In the course of the low carbon economy roadmap, the European Union is committed to reduce greenhouse gas emissions by 80-95% below 1990 levels until the year 2050. Herein, the transport sector provides high potentials for cutting emissions as it is responsible for about one quarter of European greenhouse gas emissions. The use of renewable fuels produced from renewable electricity and/or biomass can contribute in achieving this goal, especially in areas where direct electrification is challenging such as shipping, aviation, long-distance as well as heavy-duty traffic. For the future use of these fuels, an extensive infrastructure development of production capacities and corresponding logistics is needed. As a multitude of requirements must be considered, the network design of renewable fuels represents a complex planning problem. Against this background, we develop a strategic planning approach for the network design of renewable fuels. Herein, we consider the supply of relevant input materials and electricity, the demand for final products and by-products, material flows of intermediates and final products as well as options for infrastructure investments for production, storage and transport. Our planning approach is formulated as a multi-period MILP accounting for technology, capacity and location decisions to produce, store and transport renewable fuels. The model maximizes the net present value of the production network considering mass balance and capacity restrictions. The model is applied to a European case study to derive insights concerning advantageous network designs for trans-regional production networks in terms of production and logistic concepts as well as strategies for capacity expansion. We investigate to what extend locations and technological choices of the production facilities are influenced by the regional distribution of electricity and biomass as well as the fuel demand. Additionally, we analyze whether decentralized or centralized production networks may be advantageous based on the trade-off between transportation costs and economies of scale of production facilities. Furthermore, we conduct scenario analyses in order to account for uncertain parameters (e. g. renewable energy potential, fuel demand and technology costs). Based on these analyses, recommendations for policy makers and investors are derived.

■ WD-07

Wednesday, 16:10-17:25 - POT/251/H

Optimization of Technical Systems

Stream: OR in Engineering
Invited session
Chair: *Lena Charlotte Altherr*

1 - Comparison of piecewise linearization techniques to model electric motor efficiency maps

Philipp Leise, Lena Charlotte Altherr, Nicolai Simon

Battery electric vehicles, like cars or buses, must use an energetically optimized powertrain to maximize the travel distances for a given amount of stored energy. One key part within optimization models of electric powertrains is the efficiency map of the electric motor. These functions are usually highly nonlinear and nonconvex and lead to major challenges within the optimization process. To enable fast and secure solutions, it is mandatory to reduce the complexity produced by these constraints. One possibility is the usage of piecewise linearization techniques to approximate the nonlinear efficiency map with linear constraints. Within this contribution, we evaluate the influence of different piece-wise linearization techniques on the overall solution process and compare methods with and without binary variables.

2 - Designing an efficient and cost-optimal industrial cooling system using Mixed-Integer Nonlinear Programming

Marvin Meck, Tim Müller, Lena Charlotte Altherr, Peter Pelz

Next to automotive, mechanical and engineering sectors, the chemical industry is the third most important industrial sector in Germany, having yielded about 10 percent of the total manufacturing revenue in 2017 [1]. In order to manufacture high-quality chemical products, proper management of plant operations is of crucial importance. An important component of effective process control is the cooling circuit of a plant. From a purely revenue-oriented perspective, the cooling circuit poses merely a matter of cost: the revenue is independent of the functionality of the cooling system as long as the production is not negatively affected by a lack thereof. Ultimately, however, the energy costs make up a large part of the operation cost of a plants cooling circuit. With a share of 29%, the chemical industry is the most energy-intensive industry in Germany [2]. While thermodynamic boundary conditions greatly restrict the scope for reducing the energy consumption of core processes, secondary processes such as cooling offer scope for energy optimization [3]. The main components of a cooling circuit are booster stations (pumps), valves, piping, and heat exchangers as well as boilers, condensers and turbines if phase change occurs. From an energetic point of view, it is a hydraulic connection of different energy sinks with booster stations which serve as energy sources by providing the pressure head to maintain the volume flow of coolant through the system. Due to the complexity of the system topologies and the size of the solution space, one can assume that the majority of systems designed without the help of optimization methods still offer energetic and monetary improvement potential. In this contribution, we therefore present a holistic approach to reduce overall system costs. For this purpose, we model an existing - conventionally designed - real-life cooling system physically and mathematically. The technical boundary conditions of the model are provided by the operators. In order to systematically evaluate different degrees of freedom in the system topology and its operation, we formulate and solve a Mixed-Integer Nonlinear Program (MINLP), and compare the optimization results with the existing system.

[1] Revenue of the most important industrial Sectors in Germany in the years from 2015 to 2017 (in billions of euros). In Statista - The statistics portal. Access on 12th April 2019 from https://de.statista.com/statistik/daten/studie/241480/umfrage/umsaetze-der-wichtigsten-industriebranchen-in-deutschland/. Data collected by the Federal Statistical Office of Germany, data prepared by the VCI (German Chemical Industry Association). [2] Federal Statistical Office of Germany. Press Release No. 426, 2nd November 2018. [3] Fleiter, T., et al. (2013): Energieverbrauch und CO2- Emissionen industrieller Prozesstechnologien - Einsparpotenziale , Hemmnisse und Instrumente. Stuttgart: Fraunhofer-Institut für System- und Innovationsforschung.

3 - A two-phase approach for model-based design of experiments applied in chemical process engineering

Jan Schwientek, Michael Bortz, Charlie Vanaret, Johannes Höller, Patrick Schwartz, Philipp Seufert, Norbert Asprion, Roger Böttcher

Design of experiments (DoE) subsumes all methodologies for the systematic planning and statistical evaluation of experiments. Its aim is to determine the interactions between input and output quantities as precisely as possible from a minimum number of experiments. In this framework, the following main questions should be addressed: (1) How many (different) experiments should be performed and which ones? (2) And, because of measurement inaccuracies, how often should the same experiment be repeated?

Model-based DoE, contrary to statistical DoE, involves a mathematical model that describes the relationship between inputs and outputs. Such a model is usually parametrized and fitted to measured data. The model parameters, which depend on the data and the associated measurement inaccuracies, can then be adjusted more precisely by means of experimental design.

Statistical design techniques can often be proven to be optimal for linear models. However, this is no longer the case for nonlinear models. In engineering applications, where the models are characterized by physical laws, nonlinear models often lead to nonconvex experimental design problems, thus making the computation of optimal experimental designs arduous. Fortunately, statistical and linear experimental design approaches can still be exploited as initialization and globalization techniques, albeit with no guarantee of global optimality.

On the other hand, optimal selection from an infinite set of experiments can be approximated using a discrete set of candidate experiments with fixed model inputs. The corresponding experiment selection problem is a convex continuous optimization problem that can be solved to global optimality. It provides the optimal experiments among the set of candidate experiments, as well as their multiplicities (the number of times each experiment should be performed). These facts motivate a two-phase strategy that first solves the relaxed convex selection problem, and then uses this optimal selection to initialize the original problem.

In this talk, we present two initialization strategies stemming from statistical DoE and show how they can be used in a multi-start approach to compute a good local (possibly global) solution. Furthermore, we introduce the experiment selection problem and derive the mentioned two-phase approach. Finally, we illustrate and evaluate the two statistical DoE-driven approaches as well as the generic two-phase approach on DoE problems from chemical process engineering.

■ WD-08

Wednesday, 16:10-17:25 - POT/351/H

Optimization Problems in Shunting Yards

Stream: Logistics and Freight Transportation
Invited session

Chair: *Henning Preis*
Chair: *Moritz Ruf*

1 - Identification of defective railway wheels from highly imbalanced Wheel Impact Load Detector sensor data

Sanjeev Sabnis, *Shripad Salsingikar*, *Shravana Kumar Yadav*

Wheel Load Impact Detectors (WILD) are track side sensors used in railroads to measure the vertical force imposed by a wheel on the rail. The unit of the force can be Kilo Pound (Kip) or Kilo Newton (KN). The higher the force, the more damage will be imposed to both the wheels and tracks. Railroads use this measure to detect whether there are any defects in either the tracks or the wheels. An alarm is triggered if the force value is above or equal to a given threshold value and involved cars need to be set out for inspection and repair (if necessary) either immediately or at the next available repair location. Although immediate action is not required for wheels with peak kips values close to the threshold value, the damage to tracks and wheels might deteriorate (and the force imposed by a defective wheel may further increase) if defective wheels are not fixed in time. However, setting out a car when it is loaded will cause a lot of loss to railroad company. The shipment might get delayed and the network traffic might suffer from unnecessary disruptions. Therefore, the railroad has an incentive to proactively identify problematic wheels/cars and exclude them from being used for future shipments. The organizers of INFORMS RAS Problem Solving Competition 2017 made the data available in terms of force (peak Kips) values and 22 input variables that include train number, axel side, age, binary variable indicating loaded or empty status of the train etc. The problem described in the competition was to predict peak Kips values when a currently empty car would be loaded in the next trip. The results were not satisfactory and False Positive Rate and False Negative Rate obtained were very high in the range of 90%. The original prediction problem was converted into a classification problem on the basis of peak kips values in order to detect defects in railroad wheels. Peak Kips values greater than or equal to threshold value of 90 Kips defines one class, while its value less than 90 defines its complement. It is to be noted that this data set is highly imbalanced as about 99.99% of the peak kips values are less than or equal to 90 Kips and the remaining .01% are greater than 90 Kips. The statistical Methodologies that have been attempted to come up with a classification rule include (i) zero-inflated Binomial (ZIB) regression model, (ii) ZIB with L1 norm regularization, (iii) ZIB with L2 norm regularization, and (iv) Synthetic Minority Over-sampling Technique (SMOT). Out of these four methods, ZIB with L2 norm and SMOT yielded satisfactory results in the sense that for the former method the False Positive Rate turned out to be 13% and False Negative Rate turned out to be 7%, whereas for the latter method they were, respectively 15% and 16%.

2 - Train formation in shunting yards without departure tracks

Max Zien

Wagons of incoming trains are decoupled and shunted to new freight trains in so called shunting yards. In a hump yard decoupled wagons are pushed over a hump and roll into a system of classification track to build new trains. Afterwards the wagons are pushed into the departure tracks. Typically wagons are moved to departure tracks and all wagons of the classificated trains are shunted. As there are sometimes more trains to assemble than classification tracks are available, a train formation problem arises. A possibility to face this kind of problem is to introduce pullbacks. Wagons which can not assign to a classification track to form a new train are stored on a mixing track which is one designated track out of the classification tracks. On a determined time the wagons of the mixing track are pulled back over the hump and are humped again. In the newly modernized shunting yard in Halle (Saale), no departure tracks are available such that completed trains have to wait on the classification tracks until departure. Therefore the train formation problem becomes more difficult to solve as shunting capacity is more restricted compared to traditional shunting yards. The train formation problem dedicated to the specific layout of the shunting yard in Halle (Saale) is presented and to cope with the increasing complexity, variable pullbacks are introduced.

3 - Towards automated dispatching in classification yards - a holistic approach

Moritz Ruf, *Nadine Hohmann*, *Rainer König*, *Henning Preis*

In single wagonload freight, railcars are routed from origin to destination via multiple trains. The necessary railcar interchanges require disassembling and classifying processes which proceed in the hubs of the network - the so-called classification yards. Efficient processes in the yards have a large impact on the performance of wagonload freight. As yard managers make decisions mainly based on their individual experience, the development of customized decision support tools is of high relevance for the operators. In this talk, we address an operational problem encountered in classification yards which comprises the assignment of trains to tracks, the scheduling of a high variety of interdependent operational processes, and the assignment of local staff and locomotives to the processes. Although we consider a highly integrated problem, it is mostly treated as separate subproblems in the literature. We present a holistic formulation as a mixed integer linear program embedded in a rolling-horizon approach for a decision support tool. First experiments indicate the effectiveness of the approach and the plausibility of the decisions. A case-study illustrates the trade-off between solution quality and computational time when varying the optimization horizon in a dynamic environment with uncertainties.

■ WD-09

Wednesday, 16:10-17:25 - POT/361/H

Integrated Approaches for Production, Inventory and Logistics Systems

Stream: Production and Operations Management
Invited session

Chair: *Olivier Gallay*

1 - Facility location with modular capacities for distributed scheduling problems

Eduardo Alberto Alarcon Gerbier

Currently, the industries are immersed in an era in which the development of cyber-physical technologies (Industry 4.0) and cloud-based networks have the potential to redesign production systems and to give rise to smart factories. Because of it, it is necessary to investigate new concepts of network design, as well as their optimization and coordination. Furthermore, due to an increased interest for Just in Time deliveries, as well as sustainable manufacturing, decentralized and flexible (mobile) production systems are a practical proposition, because the production takes place close to the customer. This allows a higher flexibility, shorter delivery times, lower logistic costs, and reducing CO2 emissions caused by long transport distances. Therefore, the aim of this contribution is to connect the idea of decentralized manufacturing with the integrated planning of production and distribution operations, capturing this problem mathematically in a MIP model. Formally, a capacitated facility location problem has to be solved together with a production and distribution scheduling problem. The problem can be described as follows. There is a manufacturer that can produce at S different locations to serve I geographically distributed customers. Each customer orders a specific amount of a generic product. Since homogeneous production sites are assumed, the processing time is proportional to the demand of each customer. After production, each order

is directly delivered to the customer considering site-dependent transportation time. Besides, the manufacturer has at his disposal M identical modules (or production lines), which can be relocated from one production site to another generating an expansion or reduction of the total production capacity in each site. The model solves simultaneously three main arrangements. Firstly, the mathematical formulation looks for the optimal assignment of modules to production sites (location problem with modular capacities). Secondly, the MIP model assigns the customer orders to a specific site (assignment problem), and finally, the machine scheduling planning is carried out (sequencing problem), aiming to minimize overall cost produced by delivery delay, transport, module relocation, and per used facilities/modules. The paper is structured as follows. Firstly, a short introduction is presented, which also includes an overview of the relevant literature. After that, a formal description of the problem is given, followed by the mathematical model. A numerical example is used in the following section to illustrate the approach before the article ends with a summary

2 - An Efficient Decomposition Method for General Configuration Assemble-to-Order Systems
Mohsen Elhafsi, Jianxin Fang, Essia Hamouda

We consider a continuous time integrated production and inventory control general product structure Assemble to Order (ATO) system consisting of m components and n products. Components are produced in a make to stock fashion and incur a holding cost rate per unit. Component production lead times are assumed to be exponentially distributed. Products' demand arrive according to independent Poisson streams. If a product's demand cannot be fulfilled immediately, it is assumed lost thus incurring a lost sale cost. The problem is formulated as an infinite horizon discounted Markov decision process. Characterizing the optimal policy structure of such a system is known to be very challenging. As such, we propose a heuristic policy that is based on a decomposition of the general product structure ATO system. We show that such a heuristic policy possesses many properties encountered in special product structure ATO systems such as the M-, W- and Nested-product structures. For example, we show that component production is controlled via state-dependent base-stock levels and inventory allocation is controlled via state-dependent rationing levels. We show that such a heuristic is very efficient both in mimicking the optimal policy and in computational CPU time, for systems with up to 5 components and 6 products. Our results show that the cost of the heuristic policy remains within 4% of that of the optimal policy for all considered configurations. The CPU time required by the heuristic is several orders of magnitude lower than that of the optimal policy. In order to test the efficiency of the heuristic for larger systems, we develop a tight lower bound for the general product structure ATO system. We use the perfect information relaxation of infinite horizon MDP problems, to develop such a lower bound. Our results show that the heuristic continues to perform relatively very well compared to other heuristics proposed in the literature. We further show that constructing the decomposition heuristic policy for very large ATO systems remains within reasonable CPU time.

3 - Integrating Workload Smoothing and Inventory Reduction for Cross-Docking Operations
Olivier Gallay, Marc-Antoine Coindreau, Nicolas Zufferey, Gilbert Laporte

In this work, we address the operational management of the cross-docking platforms of a large European car manufacturer, and in particular the optimization of the associated container loading activities. Over a planning horizon of one week, we aim at consolidating product flows from inland suppliers to offshore production plants. Every day, products are unloaded from trucks and are then loaded into containers, which are sent by ship at the end of the week. The products that are not loaded on a container at the end of a day are stored and wait until the next day to be processed. In the considered optimization problem, the decisions focus both on the loading day of each container and on its filling with the products to be shipped. The objective is either to reduce the largest required weekly inventory space, or the weekly workload imbalance. We model the problem as a mixed integer linear program and we develop a decomposition heuristic to solve it. Whereas the exact approach is able to solve to optimality two thirds of the provided industrial instances, the heuristic can efficiently tackle the remaining larger instances. The proposed solution methodology allows the handling of complex loading constraints related to dimensions and weight of the products. Substantial gains can be achieved for both considered objectives as, compared with current industrial practices, our solutions yield an average improvement of 46.8% for the inventory reduction and of 25.8% for the smoothing of the workload. The obtained results highlight the benefit of jointly optimizing container loading and operations scheduling. Indeed, optimizing only the container loading days, while keeping the container contents fixed, would yield a gain not exceeding 2% on the largest required weekly inventory space.

■ WD-10

Wednesday, 16:10-17:25 - ZEU/114/H

Empirical Asset Pricing

Stream: Finance
Invited session
Chair: *David Christen*

1 - Short-run wavelet-based covariance regimes for applied portfolio management
Theo Berger

The decision about asset allocations is often determined by covariance estimates from historical market data. In this paper, we introduce a wavelet-based portfolio algorithm, distinguishing between newly embedded news and long-run information which has already been fully absorbed by the market. Exploiting the wavelet decomposition into short- and long-run covariance regimes, we introduce an approach to focus on particular covariance components. Using generated data, we demonstrate that short-run covariance regimes comprise the relevant information for periodical portfolio management. In an empirical application to US stocks and other international markets for weekly, monthly, quarterly and yearly holding periods (and rebalancing), we present evidence that the application of wavelet-based covariance estimates from short-run information outperforms portfolio allocations which are based on covariance estimates from historical data.

2 - Non homogeneous Markov chains in PD-estimation - A theoretical framework in the context of IFRS 9
Philipp Hofmann, Sascha H. Moells

A consequence of the last global financial crisis has been the introduction of regulatory changes regarding the accounting-based valuation of assets influenced by credit risk. The new IFRS 9 follows the common fair value-approach and - in contrast to the preceding IAS 39 - at the same time requires banks to account for potential future losses when valuing financial products. Hence, with respect to credit risk banks are required to calculate expected losses (EL) instead of incurred losses assuming a valuation referring to the balance sheet date. This new accounting policy results in the necessity of estimating lifetime expected credit losses (LTEL) and requires sophisticated mathematical modelling. In addition, according to IFRS 9 a bank is expected to model the stressed "point-in-time"(PIT)-component requiring the consideration of macroeconomic information and thus making the PD dependent of the current state of the economy. In contrast to the traditional loss estimation over a one-year period losses over multiple periods have to be accounted for. While in expected loss models the estimation of the parameters "exposure-at-default" (EAD) and "loss-given-default" (LGD) is straightforward, the determination of the parameter "probability-of-default" (PD) has attracted most attention in academia as well as in practical applications. In the existing literature different PD-models can be distinguished: While a direct way of estimating PDs models curves for every single rating class, using migration matrices prescribes an indirect approach. Migration matrices show probabilities of a rating class migration of a debtor whose credit worthiness is captured based on internal or external rating systems. Such a stochastic process described by migration matrices represents a Markov chain that can be used to calculate multi-year default rates. We follow this approach and develop a new algorithm suitable to include the PIT-component in the modelling of PDs. In detail, we adjust average one year migration matrices in a numerical procedure and at the same time recognize macroeconomic factors. Hence, the average yearly default rate of a portfolio of companies plays an important role in our approach to capture the connection between macroeconomic changes and the entries of the migration matrix of a certain year. Furthermore, we provide proofs of mathematical properties required for Markov chains and show that appropriate economic conditions will be met by our algorithm. Finally, data from corporate default reports published by the rating agency Standard and Poor's has been used to develop and test the algorithm.

3 - An empirical analysis of arbitrage opportunities in the market for German government bonds
David Christen

We test the market for German government bonds (Bundesanleihen) for arbitrage opportunities for the time period from 2011 to 2018. The linear programming approach to arbitrage (see Hodges/Schaefer 1977) is extended to assess the empirical relevance of the limits of arbitrage problems described by Shleifer/Vishny (1995): these limits include the risk that some trades that are part of an overall arbitrage strategy cannot be carried out at the bid or ask prices that are observed at the time when the trades are submitted. Moreover, arbitrage usually involves the selling or short-selling of some assets, and therefore short-selling constraints are introduced into the model. We find that arbitrage opportunities may exist in the market for several trading days even after transaction costs, provided that the arbitrageur possesses bonds that can be sold as part of an arbitrage strategy. If short-selling is not possible or expensive, arbitrage opportunities are limited or absent.

■ WD-11

Wednesday, 16:10-17:25 - ZEU/118/H

Warehousing

Stream: Logistics and Freight Transportation
Invited session
Chair: *Fabien Tricoire*

1 - Assigning items to containers to feed assembly lines: Dantzig-Wolfe decomposition and heuristic approaches

Mauricio de Souza, Diego Moura

We deal with the problem of assigning items to containers to meet work centers' requirements from a central depot. This work is motivated by a real situation encountered in the shop floor of a major automobile industry plant in Brazil, where containers are used to feed the assembly lines with the required items. We are given a set I of types of items, for example, a kind of wheel mounting bolt, rearview mirror, etc., and a set K of types of containers to handle the required items, for example plastic and metallic recipients of different sizes. Given a planning horizon T with a demand for each item i in each period t, the problem consists of assigning items to containers to meet demands minimizing holding and handling costs subject to operational constraints. Thus, a holding cost is incurred for each unity of item i remaining besides the line at the end of a period t, and a handling cost is incurred every time a transportation with a container of type k occurs in a period t. If an item i is assigned to a container of type k, then the same quantity of item i is supplied every time a transportation of a container k with item i occurs. Operational constraints impose that the same type k of container must be used to feed the line with a given item in the whole planning horizon. Besides, there is a limited number of each container k available to be used in every period.

The constraint limiting the available number of containers of type k acts as a coupling constraint on the items. Indeed, without such a coupling constraint, the assigning decision for each item could be made independently. Thus, we propose a Dantzig-Wolfe decomposition approach based on an integer programming formulation from the literature to efficiently obtain tight lower bounds to the optimum value of the objective function. The constraint limiting the available number of containers is kept in the master problem, resulting in a decomposable structure of one subproblem per type of item. The subproblem for each item can be solved in polynomial time. We also propose a heuristic based on the generalized assignment problem. For each pair type of item - type of container a feeding mode is defined by a number of times a container k will be moved with item i from the depot to the line in each period to meet demands. A greedy randomized heuristic is used to build a set of feeding modes for each pair type of item - type of container, each feeding mode has its own cost. Then, an integer programming model of the generalized assignment problem is solved to optimality to select one feeding mode per pair at minimum cost. We report numerical results on instances based on real data, and show that (i) the Dantzig-Wolfe decomposition approach is able to provide much tighter lower bounds than the linear relaxation model in short computational times, and (ii) the proposed heuristic and decomposition approaches provide small optimality gaps.

2 - Finding optimal bin locations

Thorsten Ramsauer, Philipp Hamm

In this talk we present a case study of modelling a bin location problem for real-world application at a 3PL locgistics provider. In the considered warehouse sets of bins arrive on a regular basis that have to be moved from the goods receipt area (GRA) to an assigned bin location, where they wait for the consumption of the contained materials in a predetermined consignment or assembly zone. Previously the location was chosen based on a static strategy that considered a defined set of locations for each bin in the GRA and selected a free location randomly. This resulted in unnecessary handling effort for moving the bins to their location and further to the place of consumption. Another problem that arose from this static planning was that oftentimes no location for the bins in the GRA could be found despite the fact that many bin locations where actually unoccupied. In our talk we present our solution approach to this problem that uses an integer-programming model. The objective is to store as many bins as possible while minimizing the total handling effort. Furthermore the choice of suitable bin locations is subject to numerous constraints like fire safety regulations, matching means of transport, size or weight. In addition several types of bin locations are considered that not only differ in their requirements towards the aforementioned bin properties but with regard to the quality and quantity of the contained materials as well. The formulation also incorporates the planning of bulked small load carriers that can either be decollated or planned en bloc. We present a short computational study and compare solutions produced by our model with those of the previous planning logic.

3 - Solution approaches for storage loading problems with stacking constraints

Tobias Oelschlägel, Sigrid Knust

We consider the problem of loading items into a storage area, which is constrained by a maximum number of stacks to be used, and by a maximum number of items that can be placed into a single stack. Additionally, we are given directed stackabilty constraints describing which items can be stacked directly on top of each other.

As objective functions we consider a) minimizing the number of used stacks and b) an objective function trying to minimize the number of reshuffles required in a later retrieval stage.

In this talk, we present different MIP formulations for both objective functions and compare them computationally to a heuristic approach based on tabu search.

■ WD-12

Wednesday, 16:10-17:25 - ZEU/146/Z

Bilevel and Multi-Objective Models

Stream: Optimization under Uncertainty
Invited session
Chair: *Matthias Claus*

1 - Bilevel Programming Problem under Uncertainty for a Truss Design Problem

Johanna Burtscheidt

It seems to be very natural to formulate a truss design problem as a bilevel programming problem, since structural optimization problems have an inherent bilevel form. An additional random vector models uncertain production errors, so the problem can be considered stochastic.

During the talk a risk averse formulation is presented for the described problems under stochastic uncertainty based on different special risk measures. The existence of solutions as well as structural properties of the problem formulation are investigated. In addition, the qualitative stability of the optimal value function of this model under the disturbance of the underlying Borel probability measure with respect to the topology of weak convergence of probability measures is examined. Focusing on a finite number of scenarios of the underlying random vector, numerical experiments conclude the talk.

2 - Risk-Averse Bilevel Stochastic Linear Programs

Matthias Claus, Johanna Burtscheidt, Stephan Dempe

Two-stage linear stochastic programs and linear bilevel problems under stochastic uncertainty bear significant conceptual similarities. However, the step from the first to the latter mirrors the step from optimal values to optimal solutions and entails a loss of convexity and desirable analytical properties. Taking into account that the lower level problem may have more than one optimal solution, the talk focusses on properties of the optimistic formulation under stochastic uncertainty.

Assuming that only the follower can observe the realization of the randomness, Lipschitz continuity and continuous differentiability of the objective function are established for the risk neutral and various risk averse models.

The second part of the talk examines stability of local optimal solution sets under perturbations of the underlying probability measure w.r.t. to the topology of weak convergence for models involving law-invariant convex risk measures.

3 - Applying cutting-plane methods to multi-objective robust optimization
Fabian Chlumsky-Harttmann, Anita Schöbel

Increasingly, the aspect of uncertainty is considered in multi-objective optimization problems. The concepts of point-based, set-based and hull-based minmax robust Pareto-optimality generalize the principle of minmax robustness known from single-objective robust optimization. However, so far few approaches to solve problems with both uncertainty and multiple objectives exist. We are guided by popular cutting-plane techniques that increase the number of considered scenarios gradually known from robust (single-objective) optimization and apply this technique to different scalarizations of the uncertain multi-objective problem, such as epsilon-constraints and weighted-sum scalarization. We compare this scalarization approach to a previous approach in which cutting-plane techniques are applied directly to the multi-objective uncertain problem.

■ WD-13

Wednesday, 16:10-17:25 - ZEU/147/Z

Heuristics for Graph Problems

Stream: Graphs and Networks
Invited session
Chair: *Sascha Gritzbach*

1 - Usage of Uniform Deployment for Heuristic Design of Emergency System
Marek Kvet, Jaroslav Janacek

In this contribution, we deal with an emergency service system design, in which the average disutility is minimized. Optimization of the average user disutility is related to the large weighted p-median problem. The necessity to solve large instances of the weighted p-median problem has led to the development of many heuristic and approximate approaches. Due to complexity of the integer programming problems, the exact methods are often abandoned for their unpredictable computational time in the case, when a large instance of a location problem has to be solved. For practi-cal use, various kinds of metaheuristics are used to obtain a good solution of the in-teger programming problem. Evolutionary metaheuristics as the genetic algorithm or scatter search method hold an important position in the family of solving tools. Efficiency of the evolutionary metaheuristics is influenced by keeping diversity of the current population. We focus on usage of uniform deployment of p-median solu-tions in heuristic tools for emergency service system design. We make use of the fact that the uniformly deployed set of solutions represent a partial mapping of the "terrain" and enables to determine areas of great interest. We study here the synergy of the uniformly deployed set and a heuristic based on neighborhood search, where the solution neighborhood is set of all p-median solutions, Hamming distance of which from the current solution is 2.

2 - Uniform deployment of the p-location problem solutions
Jaroslav Janacek, Marek Kvet

The uniform deployment has emerged from the need to inspect the enormously large set of feasible solutions of an optimization problem, which is to be solved by a metaheuristic due to inability of the exact mathematical programming methods to terminate the optimization process in an acceptable time interval. The objective function values of the solutions of the uniformly deployed set of solutions represent a partial mapping of the "terrain" and enable to determine areas of great interest, which deserve proper exploration. Furthermore, the uniformly deployed set of feasible solutions can represent population with maximal diversity, what is generally welcome population property in evolutionary metaheuristics. The paper deals with a notion of uniformity based on minimal Hamming distance between each pair of solutions. The set of selected solutions is considered to be uniformly deployed if the minimal Hamming distance across the set of all pairs of selected solutions is greater than or equal to a given threshold and if the set of selected solutions is maximal, i.e. there is no possibility to add any other solution. The paper contains a way of suggesting a non-maximal initial uniformly deployed set of solutions and an iterative approach to the set enlargement.

3 - Negative Cycle Canceling for the Wind Farm Cabling Problem
Sascha Gritzbach, Torsten Ueckerdt, Dorothea Wagner, Franziska Wegner, Matthias Wolf

In the ongoing process of rethinking sustainability of natural resources, renewable energy becomes increasingly important. A major contribution comes from wind energy. WindEurope states that in 2017, 11.6 % of the total electricity demand in the European Union is covered by wind power coming from 168.7 GW of installed wind power generation [1]. In a typical offshore wind farm a set of turbines generates electrical energy which is transmitted via sea cables from offshore substations to an onshore grid point. To transport turbine production to the substations, a system of cables (inner cabling) links turbines to substations where multiple turbines may be connected in series. The designer of a wind farm has various cable types available to choose from, each of which with respective costs per unit length and thermal capacities. The latter restricts the amount of energy that can be transmitted through a cable of the respective type. However, only a single cable is buried per duct to minimize line losses and to avoid damage to cables. We call the task of finding a cost-minimal internal cable layout of a wind farm with given turbine and substation positions, as well as given turbine production and substation capacities, the Wind Farm Cabling Problem (WCP).

In this talk, we consider a formulation of WCP as a flow problem on a graph where the cost of a flow on an edge is modeled by a step function originating from the cable types. We present a hill-climbing heuristic based on negative cycle canceling. Due to the structure of the cost function, certain nice properties of min-cost flow problems with linear cost functions do not apply anymore. Our algorithm addresses the arising problems by considering the line graph of the input graph. In a nutshell, our heuristic iteratively picks a value for a desired change of flow, computes the resulting change in cost for every edge, finds a negative cycle, and performs the change of flow according to that cycle. The algorithm allows the use of different strategies, for example concerning the choice of values for the desired change of flow. In its best variant, our heuristic is competitive to other approaches such as Mixed-Integer Linear Programming or Simulated Annealing and has a running time in the range of milliseconds to just under two minutes. These performance characteristics potentially allow wind farm designers to employ our algorithm in an interactive planning process. From a more general perspective, the algorithm can also be adapted to other flow problems with a variety of cost functions.

[1] WindEurope asbl/vzw. Wind in power 2017, 2018. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf, Accessed: 2019-04-06.

■ WD-14

Wednesday, 16:10-17:25 - ZEU/148/U

Behavioral Operations Management

Stream: Game Theory and Experimental Economics
Invited session
Chair: *Guido Voigt*

1 - Contracting under Asymmetric Information: Wholesale price vs. non-linear contracts
Guido Voigt, Sebastian Schiffels

We consider a setup, where a manufacturer (buyer) has private end-customer demand information that is of interest for the supplier to make a capacity decision. We test in laboratory experiments the game-theoretic cheap-talk prediction that a menu-of-contracts outperforms simple wholesale price contracts. We find that the prediction holds true for low margin products but not for high margin products. We review the behavioral factors driving this result.

2 - Agile project management - improved performance through Scrum sprints?
Tobias Lieberum, Sebastian Schiffels, Rainer Kolisch

The most prominent agile project management approach Scrum is increasingly used, while there is hardly any scientific literature addressing this concept. At the heart of Scrum is the project execution through sprints. Sprints are short-term project phases characterized by two core elements, first timeboxed progression to the next sprint, i.e. after a fixed, constant duration, and second a specific, self-contained output goal for every sprint. Very little is known about the effects of this sprint design on the execution of a project, besides higher reactivity to project changes. In one of the first scientific analyses of agile sprints, we elaborate on the research question of how agile sprints impact (a) the execution of a project's workload and (b) the degree of innovation. For (a), we decompose the sprint elements timeboxed progression and phase-specific output goals in a 2x2 experimental design. We show both, theoretically in a behavioral model and experimentally in a controlled laboratory study, that in projects with end deadline but without timeboxed progression through the project phases participants tend to spend too much time on early project phases at the expense of later project phases. We refer to this effect as Progression Fallacy. Introducing timeboxed progression alone by design mitigates this effect but does not improve the overall exerted effort. Contrariwise, introducing phase-specific output goals alone has an adverse effect on the overall performance, as increased exerted effort leads to an amplification of the Progression Fallacy. Finally, the combination of timeboxed progression and phase-specific output goals results in a positive interaction effect from a mitigation of the Progression Fallacy and higher exerted effort. We thus find statistically significant evidence for higher workload completion from working in agile sprints. For (b), we investigate the effect of timeboxed progression with phase-specific output goals on innovation. We hypothesize that the minimum specifications for every project phase are more reliably delivered than without sprints, but that the degree of innovation is less radical due to narrow bracketing. We develop an experimental design to test these hypotheses in a controlled laboratory setting and find support in pilot studies. In summary, our contribution provides strong evidence that Scrum's agile sprints result in improved output efficiency and delivery of minimum specifications but may reduce the degree of innovation.

3 - Managing System Availability - The effects of advice and decision support on performance
Cedric Lehmann, Christiane Haubitz, Ulrich Thonemann

Inventory management for service parts is a common and complex task. Inventory managers must decide on order quantities for numerous service parts in order to guarantee a certain target service level of a system.

A naïve approach to this problem is to manage inventories in a way that each service part reaches the target service level of the system. This is called item approach. However, Sherbrooke (2004) suggests the system approach that relies on a holistic view, considering the entire system. Its solution approach is to balance the cost and the availability gain of stocking one service part against the cost and increase of availability of other parts. This usually results in part service levels below or above the system target level (Sherbrooke 2004).

Although the system approach is superior to the item approach, our research indicates that the deviation from the target service level for several service parts is counter-intuitive for human decision makers. Thus, they often adjust the known optimal solution and consequently lower the performance of the inventory system.

In order to shed light on this phenomenon, we investigate how to improve the performance of inventory systems when humans are decision makers. We conduct an experiment where subjects have to decide on inventory levels for service parts in order to reach a target service level for a given system. As Baseline, subjects have to solve the task without any support. We show that the optimal system approach solution as decision support only slightly improves decisions. This effect can be doubled when the concept and the rationale of the algorithm is explained. However, a heuristic solution that prioritizes comprehensible results over maximized inventory system performance has nearly the same effect as giving optimal solutions in combination with extensive explanations.

Sherbrooke CC (2004) Optimal Inventory Modeling of Systems: Multi-Echelon Techniques (Kluwer Academic Publisher), ISBN 1-4020-7864-X.

■ WD-15

Wednesday, 16:10-17:25 - ZEU/160/H

Results and Algorithms for Bin Packing Problems

Stream: Discrete and Integer Optimization
Invited session
Chair: *Nils-Hassan Quttineh*

1 - An Asymptotic Heuristic for the Two-Dimensional Bin Packing Problem
Torsten Buchwald, Guntram Scheithauer

We present new results for the two-dimensional bin packing problem. We show how the First-Fit Decreasing-Height (FFDH) heuristic for the two-dimensional strip packing problem can be adapted to the two-dimensional bin packing problem. Using this adapted heuristic we derive sufficient conditions which ensure that a set of items can be packed into a single bin. These conditions are used to create a new asymptotic algorithm for the two-dimensional bin packing problem. The idea of this algorithm is based on a paper of Epstein and van Stee, who presented an algorithm with asymptotic performance of 2.25. The new sufficient conditions enable us to create a new asymptotic algorithm having an asymptotic performance ratio of 2.

2 - A Stochastic Bin Packing Approach for Server Consolidation with Conflicts
John Martinovic, Markus Hähnel, Guntram Scheithauer, Waltenegus Dargie

The energy consumption of large-scale data centers as well as server clusters is expected to grow significantly in the coming years, contributing to up to 13 percent of the worldwide energy demand in 2030 . At the same time, independent studies show that data centers overprovision resources to guarantee high availability, even though the energy consumption of individual processor cores is substantially large when they are idle or underutilized. Hence, balancing the supply of and the demand for computing resources is a key factor to achieve energy-efficiency. One of the approaches adopted in the literature towards this end is the seamless consolidation of workloads with the aim of switching entire servers off. However, most existing scheduling strategies regard the workloads of virtual machines as deterministic or aim at finding approximate solutions. In this article we propose an exact approach to tackle the problem of assigning jobs with stochastic characteristics – not necessarily independent – to a minimal amount of servers subject to additional practically relevant constraints. As a main contribution, the problem under consideration is reformulated as a stochastic bin packing problem with conflicts and modeled as an integer linear program. Moreover, we provide computational results based on real-world instances obtained from a Google data center to highlight the effectiveness of our approach.

3 - Modeling of a rich bin packing problem from industry
Nils-Hassan Quttineh

We present and share the experience of modeling a real-life optimization problem. This exercise in modeling is a text book example of how a naive, straightforward mixed-integer modeling approach leads to a highly intractable model, while a deeper problem analysis leads to a non-standard, much stronger model. Our development process went from a weak model with intractable run times, via meta-heuristics and column generation, to end up with a strong model which solves the problem within seconds.

The problem in question deals with the challenges of planning the order-driven continuous casting production at the Swedish steel producer SSAB. The focus is on the cast batching problem, where the objective is to minimize production waste which unavoidably occurs as orders of different steel grades are cast in sequence. This application can be categorised as a rich bin packing problem.

■ WD-16

Wednesday, 16:10-17:25 - ZEU/250/Z

Artificial intelligence

Stream: Business Analytics, Artificial Intelligence and

Forecasting
Invited session
Chair: *Birol Yüceoglu*

1 - Machine learning in additive manufacturing and certification processes in aviation
Maximilian Rosner, Denise Holfeld

Aviation is a highly regulated sector and additive manufactured products require the provision of durability approval. Currently quality assurance processes are very time- and cost-intensive, more precisely each additive manufactured part needs to be certificated in sample and full scale tests, which represent a high hurdle for the broad application of this method. Within the project AMCOCS (Additive Manufactured Component Certification Services) the process of certification is analysed based on the requirement of a new product, taking into account the design, testing, certification and production. This offers the possibility that data resulting from all involved partners can be considered. Thus, information from additive manufacturing, post-processing and material parameter determination alongside historical data from relevant tests, comprise the data basis for machine learn algorithms. This talk investigates how AI methods can be used to support decisions that lead to a successful certification and reduce unnecessary test samples in order to reduce the test effort. In a first step, the certification process is analysed, where currently fundamental decisions like design, test plans, evaluation of sample test results and online-supervision of the additive manufacturing process are done by experts manually. In the next step machine learning algorithms are applied for each focus, to make this decisions more efficient. Therefore, techniques of unsupervised learning are used to extract data-classifications, especially for historical data of classical, non-additive manufacturing. The resulting features are compared and supplemented with domain-knowledge, gathered from expert interviews and added to the above mentioned database. The combination of data from so far independent origins is the basis for supervised learning algorithms. Lastly, dependent on the actual decision to be made different methods like data preparation or manual feature extraction are used to create suited neural networks. The output of a neuronal network can be manifold. For example, the algorithm can support the expert-decision by giving an overview of possible classifications, recommendations, or a ranking of actions to take along with probabilities.

2 - Predict the influence of anti-cancer drugs by designing an effective Deep Learning algorithm
Seyyed Hassan Taheri, Amir Hossein Farzin, Mandana Fazeli Sangani

In the last decade, we have witnessed the advent of using artificial intelligence and machine learning in various fields of industry, economics, urban services, medicine, and etc. Especially in medicine, recently from deep learning to identify diseases and treat them have been great efforts. In addition, a lot of research has been done to provide Genetic drugs and predict its effects. Cancer is one of the most prevalent diseases in the 21st century, which has accelerated with urban population growth and consumption of non-organic foods. In this research, we are trying to provide a deep learning tool to help us more accurately address the problem of anti-cancer medication prediction. In recent years, there has been a great effort in identifying diseases and treating them. In addition, a lot of research has been done to provide Genetic drugs and to predict its effects. So, we are trying to propose an efficient deep learning algorithm to predict the impact of anticancer drugs. For this purpose, we have used a grid search algorithm that is appropriate for this problem. To find the best result for this problem, we had the following assumptions: The number of layers is high for training the network. The number of hidden layers has been tested from 3 to 10 layers. We received very good results in Improved excellent in MSE. In this algorithm, we used Adam optimizer. All of the network layers considered, dense. For activation function, several methods such as ReLu, Sigmond, and so on were used to get the best results. To get the best result, the lower batch size is used. Alpha TensorFlow-2 has been used for this network. The results of the comparison of this algorithm with other algorithms up to this date, such as Gradient Boosting Machines, Random Forests, Support Vector Machines on a standard data set, show that the proposed algorithm is far more efficient. Some of these criteria for comparison are their runtime, accuracy, and feasibility.

3 - Predicting egg sales using deep learning
Birol Yüceoglu, Ömer Zeybek, Defne İdil Eskiocak, Buse Mert

In this work, we present a deep learning-based forecast for egg sales at a leading FMCG retailer in Turkey, Migros T.A.Ş. We group the products based on three characteristics: tha package size, brand (national brand or store brand, also called private label), properties (regular vs. organic). For each relevant group, we predict the daily total sales for a period of 15 days. In the first part of this talk, we introduce the problem and the data set. In the second part, we explain the external data sets that are used in the forecasting, such as the prices or Google search trends. We also explain how to structure the data set based on the requirements of the neural networks, including steps such as standardization. Finally, we introduce the Long / Short Term Memory (LSTM) neural network structure and the computational experiments. The results of the deep learning-based predictions are compared to the econometric models such as autoregressive integrated moving average, (ARIMA). We discuss the results and present future research opportunities.

■ WD-18

Wednesday, 16:10-17:25 - ZEU/260/H

Battery electric vehicles and optimisation

Stream: Energy and Environment
Invited session
Chair: *Dominik Möst*

1 - Planning of fast charging infrastructure for battery electric vehicles along motorways considering the interaction with the electrical grid
Barbara Scheiper, Maximilian Schiffer, Grit Walther

The market penetration of battery electric vehicles (BEVs) is still sparse and BEVs are not yet seen as a suitable alternative to conventional vehicles, amongst others due to insufficient charging infrastructure. To accelerate the adoption of BEVs, sufficient public charging infrastructure must be installed. Especially, public fast charging infrastructure along motorways is necessary to enable long distance trips. However, deployed large scale, such charging stations cause additional load in the electrical grid, which is already challenged by increasing shares of decentralized, volatile renewable energy. As a result, spatial and temporal mismatches between energy demand and supply increase. To minimize the additional load and mismatches between demand and supply, decentralized energy stores can be used to locally decouple demand from fast charging stations and volatile renewable energy supply. Against this background, we derive a planning approach for fast charging infrastructure along motorways considering the interaction with the electrical grid. Our optimization model extends a path-based charging station location model in order to consider spatial and temporal interdependencies between charging demand, renewable energy supply, decentralized energy stores, and the electrical grid. We aim at minimizing the additional load within the electrical grid while simultaneously maximizing the share of renewable energy used for charging. We apply our modeling approach to a case study of the German motorway network and determine optimal locations of fast charging stations with integrated energy stores at motorway exits and rest areas. Based on our results, we derive recommendations for the design of a charging station network for the German motorway, detailing the number and locations of fast charging stations and the capacity of the energy stores. Additionally, we conduct scenario analyses for different shares of BEVs.

2 - Design of an electric bus fleet and Determination of economic break-even
Marius Madsen, Marc Gennat

Due to political and legal framework conditions, the focus is increasingly directed towards electric mobility, as it is locally emission-free. A significant proportion of public transport (PT) is already electrified with rail transport. Therefore, the focus is on diesel bus fleets, which are used in most German transportation companies. In this contribution, the planning and optimization of a mixed electric and diesel bus fleet for a municipal transportation company is presented. The goal and objective is to maximize the driven electric mileage without expanding the total number of buses in the fleet. Input conditions are driving plans and timetable planning must be hold. Moreover buses are to be loaded exclusively in the depot. No opportunity charging outside the depot is allowed due to the costs of the additional installation. Based on an existing timetable, routes are identified which can be completed

with a parametrizable battery capacity. Furthermore, climatic conditions and weight of batteries, which are incorporated into the specific energy requirement per kilometer, are modeled. Through an optimized circulation selection with a given number of electric buses and battery capacity, whose temporal degeneration is modeled, the electric traveled distance is maximized. The route maximization leads to lower overall costs, since the specific operating costs - in particular the energy costs - are expected to be lower for electric buses. Up to a certain number of electric buses no additional backup buses are necessary, which limits the investment costs. Thus latter consists of the local charging infrastructure and the eligible innovative share of additional electric bus costs. For the city of Krefeld the optimization results in a small electric bus fleet with specific battery costs of less than 380 euros per kilowatt-hour. The municipal company can operate this electric bus fleet without any additional costs. By varying the uncertain parameters such as energy and battery prices as well as subsidies and maintenance costs, the break-even points can be determined for an economical use of electric buses.

3 - Online electric vehicle charging with discrete charging rates

Johann Hurink, *Martijn Schoot Uiterkamp*, *Marco Gerards*

Due to the increasing penetration of electric vehicles (EVs) in the distribution grid, coordinated control of their charging is required to maintain a proper grid operation. Many EV charging strategies assume that the EV can charge at any rate up to a maximum value. Furthermore, many strategies use detailed predictions of uncertain data such as uncontrollable loads as input. However, in practice, charging can often be done only at a few discrete charging rates and obtaining detailed predictions of the uncertain data is difficult. Therefore, in this paper, we present an online EV scheduling approach with discrete charging rates that does not require detailed predictions of this uncertain data. Instead, the approach requires only a prediction of a single value that characterizes an optimal offline EV schedule. Simulation results show that our approach is robust against prediction errors in this characterizing value and that this value can be easily predicted.

Thursday, 9:00-10:40

■ TA-01

Thursday, 9:00-10:40 - POT/006/H

Algorithmic Advances for Discrete Optimization Problems

Stream: Discrete and Integer Optimization
Invited session
Chair: *Sven Mallach*

1 - Adaptation of a Branching Algorithm to Solve Discrete Optimization Problems
Maialen Murua, Diego Galar, Roberto Santana

In this paper we investigate a number of extensions and improvements to the Branch-and-Fix (BF) algorithm to deal with variants of the Hamiltonian cycle problem (HCP). BF belongs to the family of branching algorithms in linear programming, and it is based on the idea that HCP can be embedded in a Markov decision process. This recursive algorithm solves a sequence of linear programs, two at each branching point of the logical tree.

There are a number of components that influence BF efficiency. Among them, branching and fixing stages are the most important ones. Branching is crucial as an efficient branching rule can reduce considerably (several orders of magnitude) the size of the search tree. In addition, the criteria used to fix additional arcs in a branching point also affects to the algorithm's efficiency, and it is essential to avoid the generation of subcycles at this stage. Most of BF applications have focused of finding a single optimal solution for discrete optimization problems.

We consider two extensions for BF and evaluate the behavior of the algorithm in the proposed scenarios. The first introduced scenario addresses single/multiple-weighted graphs, converting the original Hamiltonian problem into the Traveling salesman problem. This is done by assigning one single weight to each arc in the graph and defining a single objective function. We also propose a generalization to a multi-objective optimization problem. In this case, two or more weights are assigned to each arc, and there are two or more objective functions defined on these weights that have to be simultaneously optimized. The core of our proposal is in considering more efficient ways of exploring the search tree when the new optimization criteria are added.

The second scenario includes a proposal to perform the branching as it is a main operation in the BF algorithm. Our proposal is based on the idea that the branching can be perform by using some criterion related to the execution of the algorithm, denoted dynamic branching, or by a external given parameter, denoted static branching.

2 - Dynamic Programming for Combinatorial Optimization: A Primal-Dual Approach Based on Decision Diagrams
Michael Römer, Andre Augusto Cire, Louis-Martin Rousseau

Discrete optimization is a fundamental methodology for solving a large array of problems in planning, scheduling, routing, and finance, to name a few. Many of such problems can be reformulated in terms of dynamic programming (DP) models, making them more amenable to solution methods that exploit recursiveness as opposed to linearity or convexity. DP techniques, however, often suffer from the so-called curse of dimensionality and are typically impractical for realistic-sized instances.

A more recent strategy to address the curse of dimensionality is to approximate the state-transition graph of a DP model using limited-size approximate decision diagrams (DDs). Specifically, one can systematically compress a state-transition graph to obtain either relaxation or primal heuristics for a DP model, yielding the so-called nrelaxed and restricted DDs, respectively. Previous literature shows nthat, when replacing the traditional linear programming relaxation by nrelaxed DDs in branch and bound, one can outperform state-of-the-art nmethods in several combinatorial optimization problems.

In this work, we extend this line of research by introducing the mnotion of DP-based dominance for decision diagrams. We define new ndominance-based feasibility and optimality conditions that are applied nto strengthen dual bounds provided by relaxed DDs. In addition, we show how problem-agnostic dominance-based reasoning can be employed to derive primal bounds from a relaxed DD.

We then propose a new primal-dual approach for solving a DP model that iteratively constructs and strengthens a relaxed DD until its associated dual and primal bounds coincide. Such method is guaranteed to converge to an optimal DP policy and does not rely on value iteration nor forward or backward recursions. Furthermore, it also becomes a novel alternative to solve combinatorial optimization problems without the need of branch and bound. We demonstrate the method for a range of classical combinatorial optimization problems such as knapsack problems and set covering.

3 - 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 a dynamic partition approach. DIOR is implemented as part of the MINLP-solver Decogo. Preliminary numerical results will be presented.

4 - On Odd-Cycle Separation for Maximum Cut and Binary Quadratic Optimization
Sven Mallach, Michael Juenger

In their groundbreaking work, F. Barahona and A. R. Mahjoub have given an informal description of a polynomial-time separation procedure for the odd-cycle inequalities. Since then, the odd-cycle separation problem has broadly been considered solved. However, as we reveal, a straightforward implementation is likely to generate inequalities that are not facet-inducing and have other undesirable properties. Here, we present a more detailed analysis, along with enhancements to overcome the indicated issues efficiently. It turns out that in practice, the effort invested when integrating our extensions has a positive effect on the solution process.

■ TA-02

Thursday, 9:00-10:40 - POT/051/H

Truck Platooning

Stream: Logistics and Freight Transportation
Invited session
Chair: *Szymon Albinski*

1 - The Continuous-Time Service Network Design Problem with Mixed Autonomous Fleets
Yannick Scherr, Bruno Albert Neumann Saavedra, Mike Hewitt, Dirk Christian Mattfeld

We consider a service network design problem for the tactical planning of parcel delivery in a city logistics setting. A logistics service provider seeks a repeatable plan to transport commodities with stochastic volume from distribution centers on the periphery to inner-city satellites. In a heterogeneous infrastructure, autonomous vehicles in SAE level 4 may only drive in feasible streets but need to be guided elsewhere by manually operated vehicles in platoons. We formulate a two-stage stochastic integer program in which the first stage determines the fleet mix and schedules robust transportation services, while the second stage decides on the routing of commodities in each demand scenario. Platooning requires a high level of synchronization between vehicles which demands the time-expanded networks to contain narrow time intervals, close to the continuous-time representation. Thus, we develop an algorithm based on dynamic discretization discovery which refines partially time-expanded networks iteratively without having to enumerate the fully time-expanded network. We conduct a computational study, in which we analyze the efficacy of this algorithm and assess the effects of stochastic demand. We further discuss the use of autonomous vehicles and platooning in city logistics.

2 - Spatial and temporal synchonization 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 dynamic planning of platoons of two trucks. We consider the problem in Euclidean space and on networks. To determine the platoons and the associated synchronized truck routes, we present an exact algorithm and several quick heuristics. 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.

3 - The Restricted Truck Platooning Problem
Szymon Albinski, Teodor Gabriel Crainic, Stefan Minner

Advances in autonomous driving technology have fostered the idea of truck platooning. Thereby, several trucks drive in close succession, connected by a data link, thus exploiting the reduced air drag due to the predecessor's slipstream. This cooperative transportation mode allows for fuel savings by up to 14% for the trailing trucks, which can help to reduce transportation cost and pollution.

In line with the sustained growth of interest in truck platooning, research on extensions and solution approaches to the MIP formulation of the combinatorial problem of routing and scheduling trucks under the option of platooning (called the Truck Platooning Problem) has been steadily increasing. However, most of the numerical studies were conducted on small problem instances and only few papers take into account realistic assumptions like drivers' wages or a maximum platoon size. In this work, we address the day-before tactical planning problem for routing and scheduling trucks. That is, we assume that there exists a platform where all carriers register their trips up to a certain cutoff date. Out of these trips, the platform creates platoons and returns to the carriers the trucks' individual routes and schedules for their tour. Since we look at long distance trips, we consider legal regulations on driving times as well as break times and daily rest periods.

We formulate this problem as a MIP on a time-expanded two-layer network and call it the Restricted Platooning Problem (RPP). In a preprocessing step, we reduce the problem size by exploiting characteristics like the trucks' time windows or maximum fuel savings. This allows us to solve RPP-instances of considerable size to optimality. In order to solve instances of larger sizes (e.g. the European or North American highway network), we focus on decomposing the problem into smaller sub-problems that are easier to solve. In our numerical study, we aim at gaining insights regarding the efficiency of this decomposition approach, the value of centralized planning and the sensitivity to different parameters of the model.

■ TA-03

Thursday, 9:00-10:40 - POT/081/H

GOR Master Theses Award Winner Presentations

Stream: GOR Award Winner Presentations
Invited session
Chair: *Stefan Ruzika*

1 - Scheduling a Proportionate Flow Shop of Batching Machines
Christoph Hertrich

In this talk we investigate the problem to schedule a proportionate flow shop of batching machines (PFB). We consider exact and approximate algorithms for tackling different variants of the problem. Our research is motivated by planning the production process for individualized medicine. Among other results we present the first polynomial time algorithm to schedule a PFB for any fixed number of machines. We also study the online case where each job is unknown until its release date. We show that a simple scheduling rule is 2-competitive. For the special case of two machines we propose an algorithm that achieves the best possible competitive ratio, namely the golden section.

2 - Vehicle Scheduling and Location Planning of the Charging Infrastructure for Electric Buses under the Consideration of Partial Charging of Vehicle Batteries
Luisa Karzel

To counteract the constantly increasing CO2 emissions, especially in local pub- lic transport, more eco-friendly electric buses are intended to gradually replace buses with combustion engines. However, their current short range makes charg- ing infrastructure planning indispensable. For a cost-minimal allocation of elec- tric vehicles to service trips, the inclusion of vehicle scheduling is also crucial. Therefore, we model and implement a simultaneous solution method for ve- hicle scheduling and charging infrastructure planning for electric buses. The Savings algorithm constructs an initial solution, while the Variable Neighbor- hood Search serves as an improvement heuristic. The focus is on a comparison between partial and full charging processes of the vehicle battery within the solution method. An evaluation based on real test instances shows that the method implemented leads to large cost savings. Oftentimes, the use of partial charging is superior to the exclusive use of full charging.

3 - Data-Driven Integrated Production and Maintenance Optimization
Anita Regler

We propose a data-driven integrated production and maintenance planning model, where machine breakdowns are subject to uncertainty and major sequence-dependent setup times occur. The uncertainty of breakdowns is addressed by considering covariates and the combinatorial problem of sequence-dependent setup times with an asymmetric Traveling Salesman Problem (TSP) approach. A data-driven approach - the combination of the TSP and machine learning - integrates prediction and optimization for the maintenance timing, which learns the influence of covariates cost-optimal via a mixed integer linear programming model. We compare this with a sequential approach, where an algorithm predicts the moment of machine failure. An extensive numerical study presents performance guarantees, the value of data incorporated into decision models and the differences between predictive and prescriptive approaches. We show the model contributes to cost savings of on average 30% compared to approaches not incorporating covariates and 18% compared to sequential approaches. Additionally, we present regularization of our prescriptive approach which yields lower cost in 80% of the instances.

■ TA-04

Thursday, 9:00-10:40 - POT/106/U

Algorithms for Nonsmooth optimization: Theory and Applications II

Stream: Control Theory and Continuous Optimization
Invited session
Chair: *Andrea Walther*

1 - Abs-Normal NLPs and their intimate relationship to MPECs
Marc Steinbach, Lisa Hegerhorst-Schultchen

We consider NLPs with equality and inequality constraints in abs-normal form and generalize kink qualifications and optimality conditions of Griewank and Walther to this general non-smooth problem class. We also compare abs-normal NLPs to general MPECs and highlight intimate relationships of respective branch problems, constraints qualifications, and stationarity concepts.

2 - Towards constrained nonsmooth optimization using Abs-Linearisation
Timo Kreimeier, Andreas Griewank, Andrea Walther

Nonsmooth optimization using the Successive Abs-Linear Minimization (SALMIN) approach has been analyzed comprehensively. In this talk we present a first extension to cover also linear equality and inequality constraints. First theoretical and numerical results will be discussed.

3 - Successive Abs-Linear Global Optimization

Andreas Griewank

Many optimization problems in machine learning are nonsmooth and require the computation of global minimizer or at least low local minima. We propose to successively approximate the given piecewise smooth objectives by a piecewise linear local model problem. For these inner loop problems we consider three global optimization methods: Global Coordinate Descent, Reformulation as Mixed Binary Linear Programm and a Target Oriented Averaging Search Trajectory. We will elaborate the latter approach in some detail and report comparative numerical results, also with steepest descent and stochastic gradient.

4 - Switching Time Optimization with Switching Cost through Proximal Methods

Alberto De Marchi, Matthias Gerdts

This work concerns the finite time-horizon optimal control of a continuous-time switched nonlinear dynamical system, where the objective functional also accounts for a state-independent switching cost. Assuming that a sequence of discrete-valued control inputs is given, the approach yields a reformulation into a switching time optimization problem. The decision variables are the time intervals in which the discrete-valued controls are applied; these are continuous-valued and possibly coupled, if the finite time-horizon is fixed. Regarding the uniform switching cost, it is related to the concept of cardinality and, inspired by sparse optimization, it can be expressed via the L0 "norm". This results in a continuous optimization problem with composite objective function, consisting of a smooth term penalizing, e.g., quadratic tracking errors, and a nonconvex term discouraging changes in the discrete-valued control input. Aiming at numerically approximating a solution to this composite nonconvex optimization problem, we adopt proximal algorithms to deal with its peculiar structure. An efficient routine for evaluating the constrained L0 proximal operator is developed and exploited to tackle problems with fixed final time. Several examples are numerically solved via both an accelerated proximal gradient method and a second-order proximal Newton-type method, demonstrating effectiveness and potential of the proposed technique. Some limitations are also highlighted. Although this work focuses on switched, possibly nonlinear, time-varying dynamics, the revealed approach may apply to a great extent to more general mixed-integer optimal control problems with switching costs.

■ TA-05

Thursday, 9:00-10:40 - POT/112/H

Railway timetabling

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Niels Lindner*

1 - Periodic timetabling with flexibility based on a mesoscopic topology

Stephan Buetikofer, Raimond Wüst, Severin Ess

Many railway companies operate with periodic timetables. The periodic event scheduling problem (PESP) was investigated by many different authors and was applied to real world instances. It has proven its practicability in different case studies. One objective of the Swiss project 'Smart Rail 4.0' is finding a way to integrate and automate processes of the railway value chain (e.g. line planning, timetabling and vehicle scheduling, etc.). In the context of an applied research project together with the Swiss Railway Company (SBB), we have developed an extension of the PESP model. The PESP-extension is based on the known, flexible PESP formulation (FPESP), i.e. we calculate time intervals instead of time points for the arrival resp. departures times at operating points. In addition our modelling approach uses a finer resolution of the track infrastructure, the so-called mesoscopic topology. The mesoscopic topology not only refers to operation points linked by driving edges, but also to the individual tracks and the allowed switches between these tracks. The mesoscopic topology allows creating timetables with train lines assigned to track paths. An additional advantage of our mesoscopic approach is that the preferred precedence of trains at operation points is determined automatically during the calculation of the model solution. Both extensions (mesoscopic topology and flexibility) should enhance the chance of generating conflict-free operational timetables on the level of microscopic infrastructure. Therefore, we will call our model track-choice, flexible PESP model (TCFPESP). A preliminary version of this model was shown last year at the OR 2018 conference in Brussel. In the presentation, we will briefly show the embedding of the model TCFPESP in the overall context of the research project. Then, we discuss the details of the mathematical formulation of TCFPESP as mixed integer linear program and show numerical results of a small case study.

2 - Blackbox Optimization Techniques for Data-driven Railway Simulation

Julian Reisch, Natalia Kliewer

The process of railway timetabling includes the simulation of a given timetable under the influence of delays. That is, primary delay distributions that affect single trains are given and the simulation computes the knock-on delays to other trains. This yields a sum of presumably more delays. The aim of a simulation is to evaluate a timetable with respect to its robustness towards such primary delays. We propose a generic framework to use any such simulation in order to not just evaluate but optimize a timetable with respect to the sum of expected delays.

The general optimization technique is blackbox optimization. The reason we choose this technique is twofold. On the one hand, the objective function can be evaluated by running the simulation with a timetable, but the derivative is almost impossible to compute. On the other hand, the objective function is not at all linear, so ordinary optimization techniques such as linear programming are not suitable. Therefore, we explore the solution space by iteratively guessing a new timetable and then evaluating the objective function, that is, running the simulation for this timetable. Since a simulation run is computationally expensive, our task is to find good guesses for new timetables so that our optimization algorithm converges fast. We deploy simulated annealing where the neighbourhood of the current state is examined which yields the next guess. Firstly, we apply a momentum method that the optimization direction that gave good results previously, is considered again. Secondly, we implement two apriori rules that push the new state in a way an expert would do.

We evaluate the approaches with the help of a simple simulation that is based on Markov chains. The methodology is to estimate empirical distribution functions for the delay propagation. This is done by counting the frequencies of delay propapgation in real world data that is provided by Deutsche Bahn. The empirical distributions then give rise to the transition matrices of an inhomogeneous discrete time discrete space Markov chain. This Markov chain models the delay propagation of a train from one station to another or of one train to its successor. We apply our optimization algorithm to the timetable of a long distance train through Germany. The result we got is that the optimization algorithm converges fast when we apply the momentum method and even faster when we also use the apriori rules.

3 - The Restricted Modulo Network Simplex Method for Integrated Timetabling and Passenger Routing

Niels Lindner, Fabian Löbel, Ralf Borndörfer

Computing high quality periodic timetables for public transportation networks is a hard optimization problem. The objective is to offer shortest travel times for the passengers, so that anticipating the passenger flow is a necessary prerequisite for the timetabling problem. However, once a timetable has been put into operation, passengers might actually choose different routes than the ones used for planning. This leads to a chicken-and-egg problem, which can be resolved by integrating both periodic timetabling and passenger routing into a single problem.

The integrated problem is usually formulated as a mixed integer program with bilinear objective, coupling the common Periodic Event Scheduling Problem (PESP) formulation for timetabling with multicommodity flow constraints for passenger routing. Given that periodic timetabling is notoriously hard itself - solving the instances from the benchmark library PESPlib to proven optimality seems out of reach - integrating passenger routes does not make the problem easier.

This motivates the use of heuristic approaches: In the context of periodic timetabling, the best-performing local heuristic is the modulo network simplex algorithm (MNS), based on the classical simplex algorithm for the minimum-cost network flow problem. The MNS has been successfully adapted to integrated passenger routing: The integrated MNS computes the optimal passenger routing for every possible simplex move, and is hence of good quality, but is very slow due to the large number of origin-destination pairs in realistic public transportation networks. Less frequent re-routings decrease running time, but also quality.

Our work refines the modulo network simplex method by reducing the number of possible passenger paths per origin-destination pair. Since

in city-sized networks, a large amount of passengers needs to change at most once per trip, we initialize our algorithm with a fixed number of short paths with at most one transfer, computed by Yen's algorithm. In the course of the algorithm, the path pool is dynamically updated with other short paths whenever this is beneficial. This method is tested on the real-world instance given by the public transportation network of Wuppertal, Germany. In both running time and solution quality, this restricted MNS turns out to be superior to the previous versions and provides a useful heuristic for the integrated periodic timetabling and passenger routing problem.

■ TA-06

Thursday, 9:00-10:40 - POT/151/H

Environmental planning

Stream: Energy and Environment
Invited session
Chair: *Dogan Keles*

1 - Tradeoffs between battery degradation and profit from market participation of solar-storage plants

Leopold Kuttner

In recent years, large-scale energy storage plant projects have been successfully integrated into the power grid. Continuous advances in battery technology drive down costs and make participation of battery systems in energy markets viable. Especially in combination with renewable power plants, such as wind or photovoltaic plants, storage technologies allow to use the full potential of renewable energy resources, thereby accelerating the transition to a carbon free energy supply. Operators of storage plants must determine schedules for their plants ahead of time in order to operate efficiently. These scheduling decisions are mainly driven by the goal of profitable market participation. But, because battery systems suffer from gradual degradation over time, which affects the profitability in the long-term, extending the lifetime of batteries must be considered as well. A key determining factor to battery lifetime and performance is the number of charge-discharge cycles. By minimizing the number of charge-discharge cycles, the lifetime of batteries can be significantly extended. Therefore, two conflicting objectives emerge: maximizing profit from market participation in the short-term versus prolonging battery lifetime in the long-term through minimization of charge-discharge cycles. This contribution presents a multi-objective mixed-integer program for operational planning of solar-storage plants that maximizes profit from market participation while also minimizing the number of charge-discharge cycles. In a case study, storage-solar plants are studied in a day-ahead market environment. Pareto optimal solutions are determined using the epsilon constraint method. Analysis of the pareto-front shows that even minor sacrifices in profit allow to significantly reduce the number of charge-discharge cycles and therefore increase the lifetime of the battery. We further analyze the tradeoff between profit and battery degradation by selecting solutions from the pareto front using the utopian point method and compare those solutions against a simple penalty approach.

2 - A flexible Bill-of-Materials improves the GRI indicators of sustainable production planning.

Ingo Frank, Frank Herrmann, Thorsten Claus

Ecological sustainability is an increasingly important challenge in the manufacturing industry, also due to stakeholders. Replacing a conventional material with an environmentally friendly material has a positive effect on the key figures for ecological sustainability. However, such material substitution is not always possible, partly for economic reasons. Environmental sustainability indicators are becoming increasingly important for evaluating companies. The Global Reporting Initiative (GRI) standard has established itself for this purpose, and it has achieved a high level of industrial significance. In general, the GRI standard defines some key figures for sustainable production and serves as an uniform reporting tool in the areas of social, ecological and economic issues. In addition to consumption figures for environmentally harmful materials and emission figures for residual materials, the GRI standard also contains indicators representing the proportion of renewable or recycled raw materials used in production. In this work, its indicators are used for the ecological evaluation of changes in production planning.

The subject of this study is material substitution along the usual hierarchical production planning in commercially available enterprise resource planning systems - e.g. the SAP system - as proposed by Hax and Meal, among others, in 1975. Hierarchical production planning consists of the levels scheduling, lot-sizing and master production planning.

In this thesis, the influence of medium to long-term planned material replacements on economic and ecological indicators is investigated. Therefore a limitation to the master production planning is made. For this purpose, it is assumed that a linear optimisation model for the master production planning (i.e. classical model) is commonly formulated in the literature. This model was extended so that products can be used with a flexible Bill-of-Materials. Too extensive use of ecologically favourable materials is prevented by quotas on the material(s) to be used. In addition, the usual target function of storage costs and costs for additional capacities, which has to be minimized, is extended by an ecological factor. This extension of the optimization model provides significantly better key figures - according to the GRI standard - than those of the classic model. This is not surprising, but it often succeeds without a significant deterioration of the objective function results of the classical model. An integration of the new model therefore does not lead to an inappropriate expansion of the additional capacity used and of the inventory that occurs. This is an interesting new problem class that significantly improves ecological sustainability.

3 - Integrated day-ahead and intraday self-schedule bidding for energy storages using approximate dynamic programming

Benedikt Finnah, Jochen Gönsch

On most modern energy markets, electricity is traded in advance and market participants must commit to deliver or consume a certain amount of energy some time before the actual delivery. In Germany, two markets with daily auctions coexist. On the day-ahead auction market the energy is traded in 60 minutes time slots and on the intraday auction market in 15 minutes time slots. Because of the slow ramp ups of nuclear and fossil power plants, these price makers trade mostly on the day-ahead market. Only the residual energy is traded on the intraday market, where the market prices fluctuate much more. The fluctuating prices and the expected price difference between these markets can be exploited by fast ramping energy storages.

We consider the decision problem of an owner of an energy storage who trades on both markets, taking ramp up times into account. Because the state space of our dynamic programming formulation includes all features of our high-dimensional electricity price forecast, this problem cannot be solved optimally. We solve the problem with an approximate dynamic programming algorithm and a benchmark approach, which does not suffer from the curses of dimensionality. We investigate the influence of the price forecast on the expected revenue. Moreover, we show that it is essential for the dynamic program to capture the high dimensionality of the price forecast to compete with a benchmark approach.

■ TA-07

Thursday, 9:00-10:40 - POT/251/H

Crew scheduling

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Cornelia Schoen*

1 - Modelling Real-World Strict Seniority Bidding Problems in Airline Crew Rostering

Magnus Björk, Paweł Pietrzak, Andriy Svynaryov

Jeppesen provides a range of crew and fleet planning products, mainly for airlines. Such problems are challenging for various reasons, including problem size, legal requirements of schedules, and company policies. Different products handle different phases of planning, such as long term manpower planning, tail assignment, crew pairing, crew rostering, and tracking.

The scope of this presentation is modelling the crew rostering problem, which is the process of assigning monthly schedules to named crew members. The rostering optimizer takes trips generated by the pairing optimizer as an input. It must take into account such aspects as costs, industry rules and regulations, quality and robustness, and also individual crew preferences (bids). Airline industry has two main approaches for handling crew bids: one is weighted fair share, where

all crew could equally likely get their bids granted. The other is strict seniority bidding, where bids are granted in crew seniority order.

In this talk, we consider several challenges associated with building a real-world strict seniority rostering optimizer. The first challenge is how to model complex business rules that determine roster legality. The rules are imposed by government regulations, the airline, union agreements etc. Rules could be classified into horizontal (affecting only one roster) and vertical (affecting several rosters). Horizontal rules are modelled using a roster generator while vertical rules are modelled as IP constraints.

The second challenge is cost function definition. In particular, the optimizer should assign the best possible roster even for a junior crew member while keeping senior crew member bids satisfied and still respecting other cost components and business constraints. It does not seem easily possible to model this requirement using a single scalar cost function. Therefore, the strict seniority problem, in contrary to a weighted fair share problem, is not solved as a single optimization problem in practice.

Jeppesen's rostering optimizers are used commercially by a large number of major airlines, solving problems with several thousands of crew members and five to ten times more trips.

2 - Strategic planning of depots for a railway crew scheduling problem

Martin Scheffler

Crew scheduling problems are one of the most important problems within the planning process in passenger rail transport. Since the problem is NP-hard using a column generation approach is a common method for solving. In addition to the need for sophisticated solution approaches, a large number of complex practical requirements must be taken into account. This includes several requirements concerning the depots (i.e. crew bases) at different planning levels. Since duties can only begin and end at one depot, the selection of suitable railway stations (locations) as depots is crucial on strategic planning level. On the one hand, it has to be taken into account that the opening of depots causes costs (e.g. rental fee for rooms). In addition, a small number of opened depots is preferred, as this reduces the administrative effort. This means it is advisable to avoid opening depots where only a very small number of duties starts. On the other hand, a small number of depots may increase the number of employees (duties) required. In practice, it is very difficult to balance these conflicting objectives because there is a lack of suitable planning approaches for integrating in decision support systems.

In order to investigate these trade-off in detail, we adapt an existing column generation approach from tactical planning level. Based on this we present the integration of the mentioned strategic planning issues by introducing a representative standard day and using Big-M constraints. The latter leads to a very weak relaxation of the master problem, which has a negative influence on the solution process. Therefore, we strengthen the formulation by decomposing the Big-M constraints and the additional use of appropriate valid inequalities.

Computational analyses are carried out on the basis of real-life instances for a multi-period railway crew scheduling problem with attendance rates for conductors of a German railway operator. This is combined with a case study for an exemplary real-life network. We can show that considerable cost savings can be achieved through a proper pre-selection of depots. Furthermore, the approach presents a suitable way of dealing with the trade off between the number of open depots and the number of required duties in practice.

3 - Crew Planning for Commuter Rail Operations, a case study on Mumbai, India

Narayan Rangaraj, Naman Kasliwal

We consider the problem of constructing crew duties for a large, real instance of operations for commuter train services in Mumbai, India. Optimized allotment of crew duties and enforcement of work rules ensures adequate safety and welfare of rail workers.

Currently, within Indian railways, decisions related to crew allotment are made manually. The main objective is to use as few crew members as possible to execute upon the timetable. This improves the efficiency of the system by increasing the average working hours of work per duty. We also have several other secondary objectives that include (a) balanced duty workloads and (b) minimization of non-working time from designated crew start and end points.

We introduce the rail crew scheduling problem, describe the working rules for the suburban commuter operations on Western Railways, Mumbai, India and propose an efficient model for preparing work schedules. The Western Railways department operates over 1,355 services per day carrying over 4 million passengers daily using 89 trainsets. We have systematically modeled over thirty constraints to be followed while preparing crew duties. The algorithm is a constructive greedy method with some enhancements, and with post-processing for balancing the number of duties as per workload and maximizing start and end of duties near the assigned crew headquarters as best as possible.

The presence of a large number of operational constraints makes the problem difficult to solve. The major constraints are on total working hours per day and over a week. The additional considerations include (a) constraints of rest between operations performed in a duty including meal breaks, (b) constraints on 2 consecutive day operations that include a night halt, (c) location of crew headquarters (for beginning and ending of duties), (d) constraints on shunting the train to and from a stabling depot, (e) geographical characteristics of individual stations, (f) constraints related to morning and evening peak hours of the day and (g) balancing total duties on a given day.

Computational experiments are performed over the current train timetables and the results of our algorithm compare very favorably with the crew duty schedules in use. For the Western Railways train timetable of 2017-18, the crew duty sets required to perform the timetable was 404. The proposed algorithm achieves crew allotment with fewer sets, promising significant savings of manpower and money.

4 - Integrated Crew Scheduling in Passenger Transport Industries under consideration of Employee Preferences

Marius Krömer, Cornelia Schoen

Due to the binary nature of the problem and the often large problem size, Crew Scheduling has always been a challenge in passenger transportation industries. Different strategies were developed to overcome the challenges; one of the most common approaches is separation of the problem into smaller problems. E.g. Airline Crew Scheduling traditionally has been separated into two planning steps: Crew Pairing, in which flights are combined into multiple-day-trips called "pairing", and Crew Assignment, in which the previously created pairings are assigned to crew members. A similar separation is used in some applications of crew scheduling for railways and other transportation industries. This separation ensures a solution in reasonable time but it sacrifices global optimality with regards to its objective cost as well as the chance to consider the employee preferences right from the start and not only in the second step - if at all. In times of staff shortage and high negotiation power of certain employee groups, consideration of employee's schedule preferences should increase employee satisfaction and thus limit employee turnover.

We present an integrated crew scheduling model with the objective to minimize cost under consideration of employee preferences. Employee preferences for different schedule characteristics are estimated from a conjoint analysis and the tradeoff between employee satisfaction and cost is analyzed. Second, we provide an overview of current state of the art solution approaches specifically for integrated crew scheduling models, and suggest a column generation method to solve our problem. Third, we analyze and discuss the benefits from integration with regards to solution optimality, as well as the challenges with regard to solution times; furthermore, we provide an overview of suitable problem sizes and structures for using integration.

■ TA-08

Thursday, 9:00-10:40 - POT/351/H

Aircraft Routing & Vehicle Routing

Stream: Logistics and Freight Transportation
Invited session
Chair: *Andreas Westerlund*

1 - A Multi-Agent-System for the Dynamic Periodic Multi-Depot Open Vehicle Routing Problem with in the context of emergency logistics

Stephan Hocke

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. 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.

2 - Optimal collection of two materials from N ordered customers with stochastic continuous demands
Epaminondas Kyriakidis, Theodosis Dimitrakos, Constantinos Karamatsoukis

A vehicle starts its route from a depot and visits N ordered customers in order to collect from them two materials (Material 1 and Material 2). Each customer has either Material 1 or Material 2. The quantity of the material that each customer possesses is a continuous random variable with known distribution. The type of Material and its actual quantity are revealed when the vehicle arrives at a customer's site. The vehicle has two compartments (Compartment 1 and Compartment 2) 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 a penalty cost is incurred that is due to some extra labor for separating the two materials when the vehicle returns to the depot to unload the materials. The travel costs between consecutive customers and between a customer and the depot are known and satisfy the triangle property. The vehicle may interrupt its route and return to the depot to unload the materials. As soon as the material of the last customer has been collected, the vehicle returns to the depot to terminate its route. Our objective is to find to routing strategy that minimizes the total expected cost for serving all customers. The assumption that the customers are ordered enables us to solve the problem by developing a suitable stochastic dynamic programming algorithm. It is shown that the optimal routing strategy has a specific structure. Numerical results are obtained by discretizing the state space.

3 - Balancing commercial and operational KPIs in aircraft routing
Andreas Westerlund

Most airlines use standard flight scheduling products to generate aircraft routings, also for the monthly planning. At Jeppesen, we regard aircraft routing as a process of its own. The standard process of treating aircraft routing as a special case of the scheduling process, and applying the same tools as used for the long-term planning leads to that opportunities for both increased revenue and improved operational performance are overlooked. Jeppesen has worked together with an airline to use a dedicated aircraft routing optimizer to optimize its operation. The results show both increased seat capacity in key markets and improved operational performance. This presentation describes the process together with results from the airline.

■ TA-09

Thursday, 9:00-10:40 - POT/361/H

Optimization in Health Care II

Stream: Health Care Management
Invited session
Chair: *Brigitte Werners*

1 - Improving Emergency Medical Services in Switzerland via traditional and soft OR methods
Michael Schmid, Christoph Strauss, Adrian Stämpfli

Today's approaches for improving Emergency Medical Services (EMS) primarily focus on efficient fleet management by optimally assigning crews to base locations and time slots. However, important factors like the role of regulatory frameworks and the interaction between EMS and hospitals are typically not considered when finding the optimal trade-off between response times and costs for a prehospital care system.

Due to the federalist structure of Switzerland and very rigid system performance indicators, the objectives of EMS, emergency departments and local governments are not aligned, which may cause the prehospital care system to drift in undesirable directions. Most Swiss EMS are under severe pressure because (regional) governments increase performance targets while freezing or even cutting financial budgets. Due to private EMS providers entering the market, resource utilization of public EMS providers decreases and the competition for (well compensated) missions increases. Fact is that many EMS are part of a hospital department with strict budgets and financial targets. Consequently, EMS can no longer solely pursue direct patient-interests. All these circumstances force EMS to pursue small operational gains that do not necessarily contribute to a sustainable long-term evolution of prehospital care in Switzerland. In this talk, we discuss challenges related to managing prehospital care systems with many highly autonomous organisations, like in the Swiss federalist system. Based on our expertise from a decade of applied research in emergency logistics, we give an overview of the applicability of classical OR methods like Discrete Event Simulation and soft OR methods like System Dynamics to support strategic and operational decision making.

2 - A Capacitated EMS Location Model with Site Interdependencies
Matthias Grot, Tristan Becker, Pia Mareike Steenweg, Brigitte Werners

In case of an emergency it is important to quickly provide emergency care for the patients. An efficient emergency medical service network is crucial as resources are limited. Therefore, emergency sites with differing capacity of ambulances are located to cover the area in the best possible way. When an emergency call arrives at a site that is currently busy, the call is forwarded to a different site. Thus, the busy fraction of each site depends on the interactions with other facilities. Mathematical models are used to carefully select facility sites and their capacity. Existing standard models make various simplifying assumptions to maintain a linear formulation. These comprise, among others, site independency and a system-wide utilization of vehicles. Typically, a higher fraction of calls originates at the city center while fewer emergencies occur at the suburbs. The assumption of an average server busy fraction may lead to an overestimation of the actual coverage quality because higher frequented sites may be overloaded and cannot serve their assigned demand. We introduce a new mixed integer programming model with an upper bound for the busy fraction of each site and site interdependence. The objective value of our formulation is thus closer to the actual coverage. We apply our mathematical model to a realistic case of a local EMS provider. The optimal results for locating sites and ambulances provided by the model are evaluated using a discrete event simulation. The performance of the emergency network can be improved compared to existing standard ambulance location models by avoiding an overestimation of the actual coverage and explicitly modelling site interdependencies.

3 - Personnel Scheduling in a Rest Home - Introducing the Five-Day Shift Schedule
Tobias Volkmer, Thomas Spengler

In this study, we examine the possibilities of a rest home to switch from a six-day shift per nurse and week to a five-day shift schedule. When using the current shift system, an increased absence rate of the nursing staff can be observed and as a result, staffing demands often stay unsatisfied. The conversion of the shift system aims to reduce the physical and psychological burden on employees. The goal of this study is to reduce employees' absences, which are mainly due to illness, and to increase their job satisfaction, so that staffing requirements can be better met in the future. For this purpose, we develop an optimization approach in the field of personnel scheduling. In particular, a tour scheduling model is formulated which determines the type and number of shift patterns to be used. In addition, we integrate elements of fuzzy control into the modeling to take the vagueness of the used data into account.

■ TA-10

Thursday, 9:00-10:40 - ZEU/114/H

Financial Modeling I

Stream: Finance
Invited session
Chair: *Elmar Lukas*

1 - Preemptive competition between two firms with different time discounts
Michi Nishihara

This paper analyzes the preemptive equilibrium of a real options duopoly game between two firms with different time discount rates. I show the order of investments, investment thresholds, and firm values in equilibrium. When the patient firm's investment cost is not higher than the impatient firm's cost, the patient firm always enters the market earlier, and its project value is higher than the impatient firm's value. When the patient firm's investment cost is higher than the impatient firm's cost, the order of the market entry can depend on the market characteristics. With smaller first-mover advantage, as well as a lower market growth rate and a higher market volatility, the impatient firm is more likely to enter the market earlier than the patient firm. Notably, in such situations, the first mover's (i.e., the impatient firm's) project value can be lower than the follower's (i.e., the patient firm's) value. The results can account for empirical findings about the order of market entry.

2 - A Real Options Approach to Determine the Optimal Choice Between Lifetime Extension and Repowering of Wind Turbines
Maximilian Heumann, Chris Stetter, Martin Westbomke, Malte Stonis, Michael H. Breitner

More than one third of the installed wind energy capacity in Germany will leave the renewable energy funding regime between 2020 and 2025. As a result, operators of affected turbines are increasingly facing the decision of choosing the most profitable end-of-funding strategy. One option is lifetime extension at the level of electricity spot market prices, whereas the other option is repowering, which is the replacement by a new and more efficient turbine. In the German case, repowered turbines correspond to the renewable energy funding regime for another 20 years. However, restrictive regulations regarding required minimum distances to settlements and other areas may impede a repowering. The resulting challenge is to determine the optimal lifetime of the old turbine and corresponding repowering timing. While the decision criteria for finding the best option follow economic principles incorporating viability analyses, its methodological determination is subject to the problem of replacement and the optimal stopping problem.

Current research tends to investigate lifetime extension and repowering separately and is limited to basic net present value analysis. By means of a real options approach, we combine two methods in order to address the question if extending the operational life of a turbine is economically viable, and if so, for how long until it is replaced by a new turbine. It may even be the case that repowering before leaving the renewable energy funding regime is more viable. The first method, which is the net present repowering value, determines whether replacing a turbine before the end of its useful life is financially worthwhile under uncertain conditions. The second method, which follows a real options approach, determines the optimal time to invest in the irreversible investment (i.e., replacing the turbine). The combination allows for continuously evaluating the two options of lifetime extension and repowering in order to choose the most profitable end-of-funding strategy and timing.

Even though the decision of choosing a profitable end-of-funding strategy is a single-entity (i.e., operator) decision, the overall decisions of the individual agents have a decisive influence on the total installed capacity of the entire German wind fleet for the upcoming decade. In order to permit a proof-of-concept and in-depth understanding of our real options approach, we apply our model to a wind farm in Lower Saxony, Germany. Subsequently, we transfer this microanalysis to all existing turbines in Germany (more than 26,500 turbines) in order to enable an analysis on macro level. By implementing comprehensive data analysis and applying our approach, we simulate the decision of every single turbine operator allowing to derive the overall lifetime extension and repowering potentials in Germany. Our case-study results demonstrate that a uniform end-of-funding strategy cannot be applied to all ageing turbines.

3 - 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.

4 - Radical or Incremental Innovation under Competition and Product Life Cycles
Stefan Kupfer, Elmar Lukas

Innovative companies not only face high investment costs but also tremendous R&D expenditures to develop a new product. Success in the R&D phase enables a company to bring the new product to market. However, all prosperous products attract competitors and motivate product imitations. Moreover, all individual products cannot be sold forever and sales are subject to a distinct product life cycle. The decision to develop an incremental or radical innovation may influence both the effect of competitors as well as the life cycle of the product. In this light the innovative company has to strategically plan its R&D and investment behavior. We model the R&D and product launch decision of company to develop a radical or incremental innovation facing the threat of a potential competitor who may imitate the product. We derive the optimal investment strategy for both competitors as well as the optimal R&D strategy for the innovative company.

■ TA-11

Thursday, 9:00-10:40 - ZEU/118/H

Operations Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Ulrich Pferschy*

1 - New efficient constructive heuristics for the two stage multi-machine assembly scheduling problem
Carla Talens Fayos, Victor Fernandez-Viagas, Paz Perez Gonzalez, Jose M Framinan

In this talk, we analyse the two-stage multi-machine assembly scheduling problem with the objective of minimising total completion time. The objective of this work is to improve the existing heuristic for the problem under consideration by proposing two new constructive heuristics. The first one is a fast-constructive heuristic, and, in the light of its results, it is inserted in a beam search based constructive heuristic that constitutes the second heuristic proposed. Consequently, a computational evaluation is performed to obtain an efficient set of heuristics using the quality of solutions obtained by each heuristic and its computational efforts as indicators. Finally, with respect to the second proposed heuristic, a beam search-based constructive heuristic, an analysis about the influence of modifying the beam width over the different iterations is performed. Additionally, some existing heuristics have been implemented and compared to our proposal.

2 - Analyzing and optimizing the throughput of a pharmaceutical production process
Sandy Heydrich, Heiner Ackermann, Christian Weiß

We study a scheduling problem arising from pharmaceutical production. Cutting-edge therapies often involve individualized medicine, where a specifically targeted drug is produced for each patient. The production process is highly complex and in particular very error-prone. Because of quality issues of the used tissue samples, the production for a single patient often has to return to an earlier step in the process or to a separate error handling step (or even sub-process). Furthermore, processing times are stochastic, adding even more uncertainty. Additional complexity arises from the fact that many steps of the process are executed by specialized machines, which can perform the same step for multiple patients at the same time, and for each step, multiple parallel machines might be available. Together, these features

form a challenging problem in the field of flow shop scheduling. Our goal is to minimize the flow time, i.e., the maximum amount of time a job remains in the process (from release to final, successful completion). We consider two different sets of questions. First, we assume that the process configuration is given and our task is purely scheduling. In an effort to carry over theoretical insights to the more complex, practical setting, we evaluate two intuitive heuristics and a third one, representing a middle ground between them, using simulations. Next, we assume that only the conceptual layout of the process is given, i.e., the different steps with their processing times and batch sizes. However, choosing how many machines to actually buy for each step is still part of the decision making process. With this problem setting, we can support strategic planning. Questions posed by our industrial partner were, for example: - Given a certain target capacity (e.g. throughput of jobs per year), how many machines per step should be purchased? (in order to direct investment) - At which step would it be most beneficial to decrease the processing time or increase the batch size? (in order to direct focus of research) Of course, the goal now is to balance the required investment with the objective value that can be obtained using different heuristics. We compare different process configurations using simulations, and observe that using a first straightforward lower bound for the number of machines per step yields not very good results. However, we identify a small number of critical steps, where adding only a few more machines improves the performance of the process significantly.

3 - Operational daily planning - a use case for the IN2SMART project

Ute Kandler, Ali Jamshidi, Denise Holfeld

As the railway industry moves from periodic preventive maintenance to condition based predictive maintenance, Stukton recognizes that its planning of possessions and the prioritisation of work in possessions needs to be more dynamic. Thus, assets must be capable of internally signaling their condition. Moreover, the condition can be measured or monitored externally. In this presentation, we propose a tool that can support decisions by planners to achieve optimal use of possessions, crews and equipment, while safeguarding timely and effective interventions which can minimize potential failures and possession overruns. To optimize the operational planning, it is important not only to combine the available resources and possessions, but also to take into account the asset status. In this uses case, Strukton includes the asset status and assess the risk that other assets, not included in the foreseen annual work plan, might fail before the next possession and make the decision to add extra work. Hence, the reliability will increase, and disruptions will be mitigated. The goals of this decision-support model can be summarized by the following key points: • Minimizing the total number of used possessions via finding and optimal allocation of work orders into possessions taking into account combination possibilities of interventions. • Avoiding unplanned traffic disruption via considering the current asset condition. • Finding an improved crew allocation with respect to the distribution of the work load and the transition time. During the optimization process, we have to consider the following constraints. • By a certain probability we are not allowed to overrun the predefined possessions. If we are doing so, we have to include penalty costs. • A certain availability of the network needs to be ensured. • Restrictions regarding the combination possibilities, i.e., sequential or parallel execution need to be considered. • Limitations on the available staff and machinery. The solution methodology is based on a heuristic approach embedded in a Monte Carlo simulation. In particular, we use clustering methodologies combined with a restricted bin packing problem to define the starting point of the meta heuristic, where use the a Monte Carlo Simulation in order to guarantee a robust solution.

4 - Rearranging jobs on a single machine

Ulrich Pferschy, Gaia Nicosia, Andrea Pacifici, Julia Resch

In many production settings, jobs arrive in a sequence determined by previous production steps or earlier logistics operations. While classical scheduling problems would compute a new optimal sequence from scratch, the given time and space constraints of real-world production environments often restrict this possibility. A similar setting arises if data values turn out to be different from the expected ones for which the sequence was originally constructed. Thus, the given sequence is no longer advantageous and should be rearranged.

In this work we consider a single-machine scheduling problem where we can alter the given sequence of jobs only by extracting a limited number of jobs from their position and reinserting them at later position in the sequence. This represents the usual setting of a conveyor belt. As objectives of the rearrangement we consider the minimization of total completion time, maximum lateness and number of late jobs. We propose mathematical programming models and optimal solution algorithms for the case where the movable jobs are identified. Also other types of technical restrictions for the rearrangement of jobs will be considered.

■ TA-12

Thursday, 9:00-10:40 - ZEU/146/Z

Algorithms

Stream: Optimization under Uncertainty
Invited session
Chair: *Huy Minh Le*

1 - Balancing of mixed-model assembly lines under random demand

Celso Gustavo Stall Sikora

In a mass customization context, a huge variety of product variations shares the same resources in an assembly line. Different processing times are compensated with buffers between stations or with the conveyor length of each station. The design of mixed-model assembly lines must consider the product variation and may be effected by the sequencing of the products. Although the sequencing of assembly lines is considered in a tactical level, an exponential number of models and the error prone processing of pieces may cause uncertainty in the product sequences. In the design of assembly lines, the assignment of tasks must be implemented before the sequence (or multiple sequencings) is defined. In this context, the balancing of assembly lines for a random sequence of given demand probabilities solved using a branch-and-bound algorithm. In each node, the performance of a paced line under random product variations is modeled as a Markov process. The resulting balancing is compared with other mixed-model balancing approaches, such as horizontal and vertical balancing. Furthermore, the effect of sequencing rules and their effect on the line's performance are investigated.

2 - Cost-efficient transmission of uniform items through logistical outsourcing - a principal-agent-approach

Alexander Herbst

In our modern fast-paced society the requirements on flexibility are rapidly growing for many companies and organizations. In order to cope with uncertain environmental influences in combination with short-dated tense order situations that overwhelm available resources, outsourcing of specific services or tasks is suitable to satisfy already agreed deadlines and thereby avoid heavy disadvantages like default costs or even the loss of longtime customers. We consider a randomized logistical setting with an entrepreneur who distributes only one type of item, e.g. ISO containers. For a given order, he has the options to either serve the entire amount with own resources or, for example during busy times, to pass on a partial quantity to a third-party logistics provider by concluding a service contract. We model the realization of such an arrangement on the basis of a principal-agent-relationship in which the agent has hidden characteristics that cannot be fully recognized by the principle. The negotiation process is pre-defined in such a way that the principle offers a limited menu of contract alternatives from which the agent can choose according to the take-it-or-leave-it principle depending on his current type. We present a holistic approach from the principal's point of view which comprises an economically reasonable design of the contract offers that take into account the a priori knowledge about the agent's possible types as well as own available distribution capacities.

3 - Robust Single Machine Makespan Scheduling-Location Problem on Trees

Huy Minh Le, Sven Krumke

In this talk, we investigate the robust single machine makespan scheduling-location problem with uncertainty in edge lengths. The uncertainty set is given in the sense that the total deviation of the uncertainty parameters cannot exceed some threshold. In order to handle uncertainty, a robustness approach is adopted with the minimax criterion (absolute robustness). We address the problem of placing a location on trees and simultaneously finding a sequence to minimize the makespan value in the worst case scenario. Further, a polynomial time algorithm for finding an optimal location and an optimal sequence on the underlying trees is developed.

■ TA-13

Thursday, 9:00-10:40 - ZEU/147/Z

Network Models

Stream: Graphs and Networks
Invited session
Chair: *Christoph Helmberg*

1 - Algorithms and Complexity for the Almost Equal Flow Problem

Till Heller, Rebekka Haese, Sven Krumke

In the maximum equal flow problem, one is given a directed graph G=(V,E) with nonnegative capacities u(e) (e in E) and homologous subsets R_1,...,R_k of the arc set E and one searches a maximum flow in the network subject to the additional constraint that all arcs in a single set R_i have the same flow value. It is known that the integral version of the maximum equal flow problem is NP-hard to solve. The fractional version is polynomial time solvable by Linear Programming. We consider a generalized version, called the almost equal maximum flow problem (AEMFP) where in addition to the sets R_1,...,R_k we are given a deviation function Delta with the meaning that, if the minimum flow value of any arc in R_i is x, then no arc in R_i can have flow value larger than Delta(x). We give an algorithm for solving the fractional version of the MAEFP in polynomial time for the case when Delta is a piecewise concave polynomial function of bounded degree and k is bounded by a constant. We also present algorithms with improved running times for the case that Delta is an affinely linear function, i.e., Delta(x)=ax+b for constants a and b. If in addition we have k=1, i.e., there is only one homologous set, even the integral version is polynomial time solvable. In contrast, if Delta is assumed to be convex, the problem becomes NP-hard to solve even in the fractional case. We show how to extend our techniques to the case of almost equal minimum cost flows.

2 - On Location Interdiction Problems in Networks

Nicolas Fröhlich, Stefan Ruzika

In this talk, we consider network location problems where an interdictor may interdict some parts of the network (e.g. vertices or edges) in order to impair the locational decisions of a decision maker (also called the locator) as much as possible. The optimal strategy of locating facilities when interdiction is possible essentially depends on the objective of the locator, for example the center or median objective. In the context of interdiction, four different problems can occur depending on the order of the actions of the two opponents and the perspective of optimization: either the locator has to locate the facilities without knowing where the interdictor will interdict the network or the interdictor has to interdict the network without knowledge of the final locations of the facilities. Both problems can be studied on the one hand from the point of view of the interdictor and on the other hand from the point of view of the locator. We present a classification scheme for these problems and prove their complexity. Further, we investigate approximation algorithms and inapproximability results for some special cases. In practical application, the results support locating critical facilities in a robust fashion and identifying weak spots with respect to locational decisions. The presented work is related to a special case of robust optimization.

This research was partially supported by the Bundesministerium für Bildung und Forschung (BMBF) under Grant No. 13N14561.

3 - Robust Network Optimization with Consistent Flow Constraints

Sabrina Schmitz, Christina Büsing, Arie Koster

The transport of a commodity can be easily represented by a minimum cost flow model, where the commodity can be identified by a flow sent through a network from a supply source to a sink with demand. In general, subcontractors can be used to transport parts of the transportation volumes. The use of subcontractors is strictly agreed by contracts. However, demand and supply are naturally subject to uncertainty and therefore influence the amount shipped or the means of transportation required. Especially for long-term contracts, this might lead to unexpected high costs. In this talk, we introduce a minimum cost flow model where on the one hand demand and supply are uncertain and on the other hand flow values of a predetermined set of arcs have to be equal in all demand and supply realizations. In the case of a discrete set of scenarios, we derive structural results, study the problem's complexity, and analyze first algorithms.

4 - Dynamic Aggregation of Time-expanded Network Flows

Anja Hähle, Christoph Helmberg

The challenges of a modern high-tech society require an ever higher level of detail in the modeling of mathematical problems. In many applications (train timetabling, production planning) time plays an important role. In general, these problems are then NP-hard. To generate a manageable solution, they are reformulated into static flow problems using time-expanded networks. Now, if these network flows are solved repeatedly within an iterative algorithm no economic calculation time can be guaranteed. We present an algorithmic framework which combines the well-known technique of Dynamic Graph Generation of Fischer and Helmberg with novel aggregation techniques on coupled time-expanded networks. Special structures in the networks as well as conditions on the objective function are used to build the time-expanded networks iteratively in an aggregated sense.

■ TA-14

Thursday, 9:00-10:40 - ZEU/148/U

Behavioral Operations

Stream: Game Theory and Experimental Economics
Invited session
Chair: *Sebastian Schiffels*

1 - Slot Management in Appointment Systems

Isabel Kaluza, Guido Voigt

Matching supply and demand efficiently in service industries may increase the provider's expected revenue. We consider the revenue management problem of a service provider (e.g., doctor) who offers a specific set of time slots (choice-set) for a workday and has to accept or deny appointment requests from consumers (e.g., patients). Consumers' demand for time slots is random (multinomial logit model). As absent demand may evoke unpleasant associations (e.g., low quality of treatment), it may be beneficial to offer only a specific subset of the available slots in order to trigger consumers' interest. In addition, reserving capacity (i.e., denying requests although there are free time slots) may avoid overtime (e.g., due to acute patients in a health care context). We contribute to the literature by analyzing under what conditions the visibility of free time slots should be actively managed by the service provider. Therefore, we model our problem as a markov decision process and develop several heuristics to derive recommended actions. Our analysis aims at providing general insights on how to manage the release of time slots in appointment systems.

2 - Newsvendor Pull-Contract Negotiations Considering Behavioral Economic Factors — Experimental Evidence

Maximilian Vincent Reimer

The competitiveness of entire industries depends on the efficiency of contracts concluded along their supply chains. They are frequently modeled by the Newsvendor problem, where a number of contracts promise to coordinate the actors efficiently. However, the well documented biases for the individual decision (order quantity), as well as for the choice of contract parameters, challenge their practical effectiveness. In many previous experiments, another important reason for losses is ignored: one contract participant is replaced by an algorithm. This can lead to a systematic overestimation of contract efficiency since the ability to maximize profits and intent to cooperate will be literally non-humane. In the experiment presented, an extension of the wholesale price contract is examined in a human-to- human negotiation, whereby explicit contract rejections are made possible. The available contract options include ones that are designed based on established bargaining solutions. Thus, it becomes possible to examine a variety of allocations away from the Nash equilibrium (the favorite of many algorithms). Firstly, the experiment reveals the real performance of different contract designs for human decision makers. Interestingly, contracts based on known bargaining solutions are shown to have a strong appeal. Explanations (based on incentivized beliefs and random choice errors) for the observed behavior are provided. Practical implications can be derived, which can stand up to the more realistic behavior of the negotiators while improving performance.

3 - Capacity allocation auctions for truthful information sharing in sales and operations planning

Sebastian Schiffels, Frank Hage, Martin Grunow

We study an intra-organizational sales and operations planning problem. Sales persons responsible for separate regions have private information on demand quantity and selling price. They compete for internal production capacity while aiming to maximize their bonus based on units sold. This leads to rationing gaming, in which sales persons inflate their demand forecast. This behavior reduces the profitability of the company. To address this problem, we develop a capacity allocation auction, which considers sales persons' reluctance to share their private information. This proposed sales and operations planning auction leads to truthful information sharing and achieves an effcient outcome in theory and in conducted experimental studies. We show that the mechanism outperforms currently used approaches. With these results, we contribute to improve sales and operations planning processes employed in practice.

4 - Inventory sharing within a warehouse that is used by several competing B2C e commerce firms

Christian Straubert

Customers are increasingly demanding faster delivery times (e.g., same-day delivery or even one/two-hour delivery). To achieve such short delivery times, the ordered products must be stored close to the customers, that is, in regional/urban warehouses. This might be feasible for large e-tailers such as Amazon.com but would mean a much sharper increase in inventory for small e-tailers (square root law of inventories) compared to a centralized warehouse.

One possible solution to this problem is inventory sharing. Inventory sharing between different competing firms in a B2C e-commerce environment means that every firm in a coalition can use the shared pool of inventory to fulfil its own demand. A special feature compared to the related topic of 'lateral transshipments' (Paterson et al. 2011) is that this inventory pool exists within one warehouse and thus there are no transshipment times/costs. The competing firms continuously share the inventory and can decide at any given time to reorder products from the suppliers. Furthermore, the retailers do not have different markets, but rather compete for the same customers. The combination of the continuous character of the problem and the direct competition between the firms distinguishes this problem from the traditional inventory sharing / lateral transshipment research. The presentation will highlight several questions that arise in the context of this new type of problem:

1.) Suppose every firm in the coalition can decide to buy a product and the amount bought is then available to all members of the coalition. Which firms should buy which products? Is a purchasing coalition necessary? How can the firms cooperate?

2.) Who or what mechanism decides on the withdrawal price of a product? How are the benefits of inventory sharing (pooling effects) distributed (e.g., Shapley value)?

3.) Generally, the pool of inventory is completely open to all members of the coalition at any time. However, reservation mechanisms might exist (e.g., for promotions). How should these mechanisms be designed?

The problem has manifold connections with existing game theoretical research (lateral transshipments, cooperative purchasing, information sharing, surplus distribution, reservation mechanisms ...). The presented research considers various existing methods from these related areas and evaluates how well they are suited for the problem. Designing a game theoretically viable system for the outlined problem is a major challenge and this contribution is intended to create a basis for future research and eventually a practicable implementation.

References: C. Paterson, G. Kiesmüller, R. Teunter, K. Glazebrook, "Inventory models with lateral transshipments: A review", European Journal of Operational Research, Vol. 210, Issue 2, 2011, pp. 125-136.

■ TA-15

Thursday, 9:00-10:40 - ZEU/160/H

Algorithmic Approaches for TSP and Routing Problems

Stream: Discrete and Integer Optimization
Invited session
Chair: *Stefan Irnich*

1 - On the Hamiltonian decomposition and the 1-skeleton of the traveling salesperson polytope

Andrei Nikolaev, Anna Kozlova

A Hamiltonian decomposition of a regular graph is a partition of its edge set into Hamiltonian cycles. The problem of finding edge-disjoint Hamiltonian cycles in a given regular graph plays an important role in operations research, coding theory, privacy-preserving distributed mining algorithms, and other areas. Our main motivation for this problem comes from the field of polyhedral combinatorics.

The 1-skeleton of a polytope P is the graph whose vertex set is the vertex set of P and edge set is the set of geometric edges or one-dimensional faces of P. The study of 1-skeleton is of interest for the development and analysis of combinatorial algorithms. On the one hand, various algorithms for perfect matching, set covering, independent set, a ranking of objects, and problems with fuzzy measures are based on the vertex adjacency relation in 1-skeleton and the local search technique. On the other hand, some characteristics of 1-skeleton, such as the diameter and the clique number, estimate the time complexity for different computation models and classes of algorithms.

We consider the traveling salesperson polytope defined as the convex hull of all possible Hamiltonian tours in the complete graph. It is known that the question of whether two vertices in the 1-skeleton of the traveling salesperson polytope are nonadjacent is NP-complete. A sufficient condition for nonadjacency can be formulated as a combinatorial problem. For two given Hamiltonian tours, we consider their union as a 4-regular multigraph. If the union multigraph contains at least two different Hamiltonian decompositions, then the corresponding vertices of the traveling salesperson polytope are not adjacent.

We establish that for special classes of Hamiltonian tours: pyramidal tours and pyramidal tours with step-backs the Hamiltonian decomposition and the vertex adjacency problems can be solved in linear time.

For the general case of the problem, we consider the heuristic algorithms based on the local search technique: the simulated annealing and the tabu search. We generate the candidate state as two complementary vertex-disjoint cycle covers of the union multigraph. A disjoint cycle cover of a graph can be found in polynomial time by transforming the problem into a problem of finding a perfect matching in a larger graph. The objective function to minimize is the total number of connected components in the cycle covers. We construct a neighbor candidate state by finding edges of one cycle cover with endpoints in two different connected components of the other cycle cover and adding them to the queue of fixed edges.

The heuristic algorithms solve the Hamiltonian decomposition problem up to the union of two Hamiltonian tours on 10 000 vertices. This approach shows particularly good results for random Hamiltonian tours since the corresponding multigraph has many different Hamiltonian decompositions.

2 - Solving the Multiple Traveling Salesperson Problem on Regular Grids in Linear Time

Lisa Knoblinger, Philipp Hungerländer, Anna Jellen, Stefan Jessenitschnig, 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, so the problem can be solved in linear time.

Our research is motivated by several real-world applications, for example delivering goods with swarms of unmanned aerial vehicles (UAV) or search and rescue operations. Considering regular grid structures allows us to divide large search areas in several equal-sized squares, where we choose the coverage as large as the sensor 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. Furthermore, we developed a combinatorial algorithm to find MTSP-tours on specific grid structures.

Based on the results of our MILPs, combinatorial counting arguments and the establishment of explicit construction schemes we are able to find optimal mTSP solutions for specific grid sizes, depot positions and numbers of salespersons in linear time.

3 - A branch-and-cut algorithm for the soft-clustered vehicle routing problem

Katrin Heßler, Stefan Irnich

The soft-clustered vehicle routing problem is a variant of the classical capacitated vehicle-routing problem (CVRP) in which customers are partitioned into clusters, and all customers of the same cluster must be served by the same vehicle. In contrast to the non-soft variant, a cluster must not be served completely before the next cluster is served, but visits to customers of the same cluster can be interrupted by visits to customers of another cluster. We introduce a new two-index formulation of the problem and solve it with a branch-and-cut algorithm. In addition to problem-specific cutting planes for clusters, known valid inequalities for the CVRP can be adapted, e.g., MTZ-based subtour-elimination constraints, capacity cuts etc. We compare different model formulations and separation procedures. Computational results on benchmark instances show the usefulness of the new branch-and-cut.

4 - Branch-Price-and-Cut for the Soft-Clustered Capacitated Arc-Routing Problem

Stefan Irnich, Timo Hintsch, Lone Kiilerich

The soft-clustered capacitated arc-routing problem (SoftCluCARP) extends the classical capacitated arc-routing problem (CARP) by one additional constraint: The required edges are partitioned into clusters and feasible routes must respect the soft-cluster constraint, that is, all edges of the same cluster must be served by the same vehicle. We design and analyze different branch-price-and-cut algorithms for the exact solution of the SoftCluCARP. The pricing subproblem is a variant of the shortest-path problem with resource constraints (SPPRC), which is in many other applications routinely solved with dynamic-programming labeling algorithms. Previous work on the node-routing variant of the problem, the soft-clustered vehicle-routing problem, has however revealed that pricing problems even for small-sized instances are extremely hard to solve with labeling. The main contribution of our work is therefore the modeling, solution, and comparison of two associated branch-and-cut (BC) algorithms for the pricing subproblem. The first BC approach relies on an adaptation of a model and algorithm of Aráoz et al. (2009), in which the evenness of the subgraph representing an optimal route is ensured using an exponential family of valid inequalities (an adaptation of the well known blossom or odd-cut inequalities). In contrast, the second approach exploits a model originally developed for windy clustered postman problems (Corberán et al., 2011). We can prove that when this model is applied to subproblems arising from undirected SoftCluCARP instances, its flow variables only take values 0 or 1, that is, it can be assumed that they are binary. In the resulting model, the evenness of the subgraph is directly imposed by flow-conservation constraints. Our computational analysis compares different setups for both BC algorithms. Preliminary tests of the overall branch-price-and-cut have shown that some medium-sized SoftCluCARP instances can be solved to optimality (for example with up to 100 vertices, 100 required edges, and 35 clusters).

■ TA-16

Thursday, 9:00-10:40 - ZEU/250/Z

Forecasting

Stream: Business Analytics, Artificial Intelligence and Forecasting
Invited session
Chair: *Julius Mehringer*

1 - A benchmark on a new approach for the automation of energy forecasting

Martin Seidler, Sabine Ritter, Maria Jüttner

Each solid planning process in the energy sector is based on forecasted energy data such as energy demands. These forecasts mainly rely on historical data exchanged between participants of the energy market.

In the underlying forecasting processes, the data must first be collected in order to be checked for errors and corrected if necessary. Currently, this data processing step can be easily automated. However, subsequent decisions required in these forecasting processes are typically performed manually by human operators. Such decisions include the analysis of characteristics specific to each energy data set, the selection of suitable forecasting models, the configuration and execution of said models, the monitoring of forecasting results, and the (daily) correction of forecasting model configurations. These decisions are compounded by the rapidly growing amount of energy data available for forecasting due to the widespread introduction of smart meters and the ubiquity of Internet-of-Things (IoT) Services. As a result, the demand for human resources for the performance of forecasting tasks is likewise rapidly increasing.

In this presentation, a new intelligent decision support system (IDSS) for the automation of the entire forecasting process on energy data is presented. The IDSS is able to process and analyze input data fully automated. Many statistical tests and transformations were done with the aim of data understanding, detrending and pattern recognition. It detects, for instance, data gaps, trends, intrinsic relationships and holidays. In dependence of the results of the analysis and the desired time horizon of forecast, the forecast model is automatically selected and parameterized. The hybrid model is build out of regression, random forests and artificial neuronal networks (ANN). In conclusion a forecast model for every specific input data set is generated.

This automatic approach is compared to the manual forecasting process with respect to the amount of time required to generate and the quality of forecasting results. For comparison purposes, a fixed set of test data is used by both, the automatic approach and a human operator (Maria Jüttner, forecasting expert at a municipal utility company in central Germany) for the generation of forecasting results.

The automated forecasting process for the given input data is performed within just a few seconds, providing forecasting results that are approximately similar to the results of the human expert concerning quality.

The IDSS is implemented to a commercial, industry-approved, product.

2 - Predictive Demand Planning - A hybrid cloud based forecast algorithm

Tony Alexander

In today's volatile and uncertain markets, accurate forecasting of customer demand becomes a key factor to success. Consequently, it is an essential process for the strategic orientation of a company. Demand Planning deals with the prediction of customer demand for the product and service business. Since in times of digitalization more and more business processes take place in a VUCA environment (volatility, uncertainty, complexity, ambiguity), the importance of Demand Planning has increased enormously over the past years. The main goal of demand planning is to achieve a high forecast accuracy while being able to promptly react to market changes. High forecast accuracy has significant influence on the correct procurement of materials, the production capacity planning of employees, machines and materials as well as on the customer delivery time and therefore on customer satisfaction. Since January 2017, we have been deploying a self-developed forecasting algorithm that generates forecasts and enables quantitative Demand Planning. The predictions are based on statistical methods, machine learning concepts and includes more than 10 different methods e.g. neural networks, exponential smoothing approaches and regression models. Based on historic data the algorithm selects continuously the best suited forecast and sets the optimal parameters for every product automatically. By minimizing the error in the trainings phase of every considered statistical method an optimal parameterization is calculated. The cloud based algorithm predicts the demand in our use case for the upcoming 2 years on a monthly basis. Furthermore, it is simply possible to scale the approach on a weekly, daily, hourly etc. basis and predict an arbitrary time period. The Predictive Demand Planning (PDP) algorithm has increased the forecast accuracy of our Business Units by up to 60% on a product level. As a consequence, we minimized the number of missing parts in production orders while reducing our stock level at the same time. Furthermore, benchmarks and prototyps show the uniqueness of our approach within the Siemens company in terms of their wide scope of considered statistical methods, an unbiased forecast with a high performance as well as giving immediate forecast results on demand.

3 - Short-term product price forecasting to schedule consumers' purchase time decisions

Benjamin Buchwitz, Anne Falkenberg, Ulrich Küsters

Price Comparison Sites for airfares not only list prices of multiple sellers but often also offer services to advise customers on the optimal purchase time decision. Surprisingly, comparable recommendation services for electronic consumer goods are not in place even though they account for a large share in the e-commerce market. Reasons for this are the huge number of retailers in the consumer goods industry, the opaque and non-transferable relationship between product

predecessor and successor as well as individual statistical properties of the underlying time series data. As research shows a large portion of customers are opportunistic about the time of purchase and highly price sensitive when comparing homogenous goods. This is especially true for bargain-hunting and strategic customers, who prefer buying at sufficiently low prices and schedule their purchase with respect to instantiated past and expected future price developments. To create a consumer-oriented decision support system, it is necessary to predict future prices over a given timeframe and derive explicit recommendations that advise customers to either buy a product directly or to delay the purchase. Due to this setting, the lowest price over a group of retailers for a given product is especially important. Historic minimum price time series in case of electronic consumer goods have specific characteristics such that prices deteriorate over time, price changes occur irregularly, which is why there are calmer and more active phases as well as entirely constant segments during a product's life cycle. We develop a framework that allows issuing dichotomous short-term buying recommendations using an exponentially-weighted markov-switching model in combination with a customized bootstrap approach. The generated predictions indicate whether the price declines within a pre-specified future horizon. We repeatedly apply the procedure to a large dataset with real product prices. This allows for a statistical but also economical evaluation in terms of real gains and losses caused by adhering to the issued recommendations. The results show that the proposed model has multiple benefits over model-free benchmark strategies as well as traditional forecasting approaches.

4 - Spare part demand forecasting with machine learning approaches

Julius Mehringer, Christian Menden

Predicting spare parts demand for the time period after production ceased is a central issue in supply chain management in order to reduce costs in terms of storage, transportation, disposal, finance and to maintain a desired level of customer satisfaction. This paper evaluates machine learning approaches to (i) find patterns in and (ii) forecast demands for a large dataset of master and consumption data from 1985-2017 stemming from a big manufacturer of household goods. More specifically, we apply different clustering methodologies with varying distance measures and parameter calibrations to determine products that share similarities in terms of (i) master data and (ii) consumption patterns. We use these clusters to construct predictions for "new" products where historical data is scarce using the data from similar (older) products where more data is already available. To this end, we use diffusion models and artificial neural networks. Our results indicate that this step-wise approach of combining clustering and forecasting methods yields significantly better forecasting results than a baseline model and improves the spare parts planning and controlling process.

■ TA-17

Thursday, 9:00-10:40 - ZEU/255/Z

Special Session on Business Applications II

Stream: Business Track
Invited session
Chair: *Philipp Hungerländer*

1 - A heuristic for locomotive scheduling with maintenance constraints and assignment restrictions

Philipp Hungerländer, Sarah Frisch, Bernhard Primas, Dominic Manuel Weinberger

The Locomotive Scheduling Problem (LSP) plays a crucial role in the railway industry. The task consists in assigning a fleet of locomotives to a set of scheduled trains. Typically, there are two key objectives of interest: (a) using as little locomotives as possible, and (b) minimizing the total number of deadhead kilometers.

In this very basic version of the problem, the problem can be formulated as a Mixed Integer Linear Program (MILP), which can be used to solve most real-world instances in reasonable time. However, in practical applications there are many additional requirements that need to be considered such as maintenance constraints or constraints on the number and types of trains and routes a locomotive can serve. If combinations of such requirements are added to the standard LSP model and solved by a MILP, even small instances become intractable, making an alternative solution approach necessary.

In this talk we present an efficient heuristic that is capable of handling a large body of requirements. The heuristic starts with the empty assignment. Then, we iteratively assign trains to a locomotive in a depth-first search manner, where in each step we make sure that all constraints remain satisfied. The algorithm stops when all scheduled trains are assigned to a locomotive.

Our heuristic is evaluated thoroughly using real-world data provided by Rail Cargo Austria, the largest Austrian rail freight transportation company. The results show that our heuristic yields high-quality solutions, both in terms of the objective function and practical applicability, while only requiring little computation time.

2 - Railway driver timetable optimization using LocalSolver

Tiphaine Rougerie

Workforce timetable optimization can be subject to multiple legal constraints. We present here the specific case of train drivers' timetable for a French railway company. The goal is to create a planning of all trips and resting periods in a minimum number of weeks.

The drivers will follow a shared timetable, each with a different offset. The timetable is a loop that each driver starts at a different week so that all the trips are assigned exactly once. Each week corresponds to the start of a driver's schedule, hence a minimum number of weeks is the same as a minimum number of drivers to assign to this timetable. Many constraints of rest and work days must also be considered and will be presented in this talk, among which the number of successive work Sundays, the number of successive trips, and a mandatory rest if a trip finishes too late and is not followed by another one.

This complex model has been solved using LocalSolver. It has been decomposed into three sub-models, each optimizing a specific view of the problem. The first model is a pairing model that matches an outward and a return journey, making sure that all drivers are back to the departure city at the end of two journeys. It gives an initial feasible solution to the second model which orders all the trips: it is a permutation problem that can be modeled using LocalSolver's list variable, as in a Traveling Salesman Problem. An oracle, implemented as an external algorithm making use of LocalSolver's Native Function, handles the evaluation of solutions. A third boolean model assigns rest days and office work days in between traveling days.

3 - Multi-objective simulation-based headway optimization for the Viennese subway network

David Schmaranzer, Roland Braune, Karl Doerner

Urban mass rapid transit systems (e.g., subway, metro, tube, underground, heavy rail) are a critical component of successful cities. They were introduced to improve movement in urban areas and reduce congestion. These motives remain valid but also are reinforced by pedestrianization, tourism, environmental demands, and continued population growth. Vienna's population - like most cities around the globe - is growing, and likely will exceed 2 million by 2025. Such networks are ubiquitous, such that 25% of cities with a population of 1 million, 50% with 2 million, and all cities with a population above 10 million host them. In some cities, they have existed for more than a century, and there are significant similarities among the different networks, despite the unique cultures, economies, and historical developments. Subway networks also tend to experience similar peak times, in the morning and afternoon, reflecting increased demand by employees traveling to or from their workplaces. In turn, the same issue confronts all subway systems: Fluctuating demand must be met by adjusting transport capacity (i.e., releasing enough trains). The term headway refers to the the time difference between consecutive trains (e.g., 3 minutes). Changes to headway (or its inverse frequency, defined by trains per time unit) might lead to overcrowded stations and trains, unless they are carefully planned. This challenge constitutes the transit network frequencies setting problem (TNFSP), which, in our case, seeks to balance capital and operational expenditures (e.g., infrastructure preservation, potential expansion) against passenger satisfaction (i.e., service level). Costs are measured in productive fleet mileage and the service level is measured in mean waiting time per passengers. Practitioners are often interested in not one but several optimized solutions from which they can choose or, if possible and reasonable, combine them. So we propose a multi-objective simulation-based headway optimization scheme for urban mass rapid transit systems that is inspired by a real-world case but generic enough to fit other cities' complex rail-bound public transport systems. The underlying simulation model has several stochastic elements. The fluctuating demand is based on hourly origin-destination-matrices based on mobile phone and count data.

Vehicle turning maneuver times are time-dependent, and the vehicle travel and passenger transfer times are direction-dependent. As a microscopic element, passenger distribution along platforms and within trains is considered. We also propose a two-phase algorithm which is a combination of the single-objective covariance matrix adaptation evolution strategy (SO-CMA-ES) and a problem specific multi-directional local search (MD-LS). In the computational study, we compare a multi-objective covariance matrix adaptation evolution strategy (MO-CMA-ES), and a non-dominated sorting genetic algorithm (NSGA-II) with our proposed method.

4 - Technician routing and scheduling applied to street furniture maintenance

Nicolas Blandamour

A company specialized in street furniture advertising has to perform a lot of actions on outdoor furniture: change the ads, clean up the panels, make some control or reparations, ... Since each street furniture element has its own specificities and location, operations to complete on it requires different skills and must be executed with different frequencies. For example, a bus shelter must be cleaned each week, while an electrical control on a digital advertising panel must be performed once a year and requires specific tools.

To ensure equality between the agents responsible for performing interventions on the street furniture, a planner must find a schedule that balances the working time between agents despite their different skills, while minimizing the total working time. The problem becomes difficult as the amount of furniture is important: up to 15000 street furniture elements for which interventions should be split between up to 35 agents.

Moreover, the corresponding optimization problem must deal with specific business rules leading to several conflicting objectives: cluster geographically the set of interventions of each agent, optimize the routes and balance the working time charges.

This talk will present the different techniques designed to solve this problem with LocalSolver (clustering, a modified capacitated vehicle routing problem followed by a smoothing model) and the results on real-world instances.

■ TA-18

Thursday, 9:00-10:40 - ZEU/260/H

Risk and Uncertainty in Supply Chains

Stream: Supply Chain Management
Invited session
Chair: *Martin Hrusovsky*

1 - Supporting sustainable freight transport by introducing innovative planning approaches

Martin Hrusovsky, Emrah Demir, Werner Jammernegg, Tom van Woensel, Tina Wakolbinger

The internalization of trade and changing conditions on the market increase the complexity of transport planning. On one hand, customers require shorter lead times, smaller quantities and on-time deliveries. On the other hand, transport planners are confronted with high demand volatility, increasing number of disruptions and delays, and innovative logistics concepts (e.g., physical internet), which require substantial changes in organization of transport operations. In addition to that, the need for more sustainable transport has become more important for all stakeholders. The described changes seem to be favorable mainly for road transport that has the highest share on modal split in Europe. This might have several reasons, among others its high flexibility, adaptability and support in available transport management systems. However, road transport is also responsible for a significant part of the increasing CO2-equivalent emissions from transport sector and the limited capacity of road infrastructure together with growing traffic volumes increases the risk of disruptions. Consequently, supporting alternative modes, such as rail or intermodal transport, might contribute to more efficient and environmentally friendly transport operations. When comparing rail or intermodal transport to road, it is obvious that the planning process for these modes is much more complex due to the higher number of involved actors and therefore requires longer time, which decreases their competitiveness. Moreover, the support for these modes in terms of available software and optimization models is limited. This is valid not only for planning but especially for the transport monitoring and execution phase, where reactions to disruptions are necessary. In order to respond to these challenges, we present two case studies for supporting more efficient planning of intermodal and rail transport. In the first case study, a hybrid simulation-optimization approach for operative intermodal transport planning and monitoring is presented. Within this approach, transport plans are optimized on daily basis according to economic and environmental criteria taking into account current traffic situation and potential disruptions. In addition to that, transport execution is monitored and the influence of disruptions and their duration on transports is analyzed. Moreover, three different policies that might be used as reaction to an identified disruption are compared. Whereas the focus in the first case study is on the optimal routing of goods that are transported within the network, the second case study deals with the availability of rail cars for these transports since it is concentrated on tactical equipment planning and management. Here, the inefficiencies in the current planning processes are revealed and possibilities for improvement and optimization are discussed.

2 - Manufacturing Network Design in Pharmaceutical Supply Chains in the Light of Uncertain Production Approval Times

Gregor Blossey, Gerd J. Hahn, Achim Koberstein

Traditionally high profit margins in the pharmaceutical sector have created largely underperforming and irresponsive supply chain structures. In combination with increasingly competitive and volatile markets, this resulted in a growing number of drug shortages in recent history. These stock-out situations do not only diminish a company's revenue but more importantly are a threat to patient's health. To counter this development, an elevated level of flexibility within the manufacturing network provided by improved capacity management and product allocation decisions is required. These decisions, however, are subject to factors of uncertainty, some of which are unique to the highly regulated pharmaceutical sector. Manufacturing processes, for instance, require approvals by local authorities each time a product is initially introduced to a facility. The time it takes to acquire such a production approval is highly uncertain and can range from a couple of months to three years. This large variation affects allocation decisions and is, hence, of great concern for planners in the industry. To address this issue, a MILP model is developed to investigate the influence of uncertainties in demands and production approval times on the network design. The model aims to improve capacity management for multiple products under life cycle demand. Outsourcing options and product allocation decisions are also considered as a means to generate flexibility and increase responsiveness. Furthermore, a numerical study motivated by a real-life case of a global pharmaceutical company is presented.

3 - Effectiveness of Transshipment and Expediting in Disruption Risk Mitigation

Mualla Gonca Avci

Due to the global competition, firms employ global sourcing and outsourcing strategies to maintain their target service level at low cost. However, these strategies induce vulnerabilities against disruptions as they extend supply chain networks to global scale and increase the complexity of the operations. Disruptions are rare, but severe events that incur drastic impact on supply chain performance. In this study, a supply chain planning problem with lateral transshipments and expediting is addressed in presence of disruptions. The objective function of the problem is a weighted aggregation of average supply chain cost and CVaR. To solve the problem, a simulation-based optimization algorithm is proposed. To investigate the effects of sourcing flexibility strategies on supply chain performance, a set of computational experiments are performed on an illustrative case. The results reveal that lateral transshipment provides better CVaR performance without a significant deterioration in the average performance. Besides, the results reveal that expedited shipment is effective in reducing stock-outs despite it increases average supply chain cost.

Thursday, 11:10-12:00

■ TB-03

Thursday, 11:10-12:00 - POT/081/H

Plenary Presentation Roman Slowinski

Stream: Plenary Presentations
Invited session
Chair: *Sophie Parragh*

1 - Constructive Preference Learning for Multiple Attribute Decision Aiding
Roman Slowinski

Identification of Decision Maker's (DM's) preferences is crucial for multiple attribute decision aiding. We present a constructive preference learning methodology, called Robust Ordinal Regression, for Multiple Criteria Decision Aiding, for Group Decision, and for Decision under Uncertainty. This methodology links Operational Research with Artificial Intelligence, and as such, it confirms the current trend in mutual relations between OR and AI. It is known that the dominance relation established in the set of alternatives evaluated on multiple attributes (criteria, or voters, or states of the nature) is the only objective information that comes from the formulation of a multiple attribute decision problem (ordinal classification, or ranking, or choice - with multiobjective optimization being a particular case). While it permits to eliminate many irrelevant (i.e., dominated) alternatives, it does not compare completely all of them, resulting in a situation where many alternatives remain incomparable. This situation may be addressed by taking into account preferences of the DM or a group of DMs. Therefore, decision aiding methods require some preference information elicited from a DM or from a group of DMs. This information is used to build more or less explicit preference model, which is then applied on a non-dominated set of alternatives to arrive at a recommendation presented to the DM(s). In practical decision aiding, the process composed of preference elicitation, preference modeling, and DM's analysis of a recommendation, loops until the DM (or a group of DMs) accepts the recommendation or decides to change the problem setting. Such an interactive process is called constructive preference learning.

Thursday, 13:15-14:00

■ TC-02

Thursday, 13:15-14:00 - POT/051/H

Semiplenary Presentation Niels Agatz

Stream: Semiplenary Presentations
Semi-plenary session
Chair: *Margaretha Gansterer*
Chair: *Stefan Irnich*

1 - Operations Research Opportunities for Future Urban Mobility
Niels Agatz

Rapid urbanization increases transportation flows and thereby traffic congestion and emissions. Air pollution poses a serious health risk in many cities around the globe. At the same time, technological developments are changing the transportation landscape with the advent of autonomous vehicles (e.g., drones), ridesharing and crowd logistics. These changes give rise to new opportunities and challenges. In this talk, I will discuss how operations research can contribute to making urban mobility smarter, more equitable and more sustainable. I will provide examples based on our recent research in this area.

■ TC-03

Thursday, 13:15-14:00 - POT/081/H

Semiplenary Presentation Eleni Pratsini

Stream: Semiplenary Presentations
Semi-plenary session
Chair: *Harold Tiemessen*

1 - The industrial perspective of Analytics
Eleni Pratsini

The last few years saw a tremendous interest in the use of Advanced Analytics tools to analyze data, extract insights and support decision making in complex environments. The recent explosion of available data and advances in computational power have also renewed interest in Artificial Intelligence, enhancing the trend and augmenting the toolset while striving for a natural interaction between humans and machines. Great advancements have been made in these areas with some organizations successfully adopting and deploying Analytics and AI methods as they embark on their digital transformation journey. However, a number of challenges still exist such as: data acquisition from different types of sources; establishing links among different data types using both structure and content; dynamic, real-time processing of data; scalability for analytics and query processing, just to name a few. These and other challenges can prevent businesses from even starting their Analytics journey or not completing it to the extend they would like, thus leading to a varying level of adoption in industry. This talk will present the industrial landscape and adoption of predictive and prescriptive analytics, highlight the integration with AI and through the use of applications motivate some of the advanced technologies, point out the practical and research challenges and highlight the business benefits.

■ TC-06

Thursday, 13:15-14:00 - POT/151/H

Semiplenary Presentation Edoardo Amaldi

Stream: Semiplenary Presentations
Semi-plenary session
Chair: *Janis Sebastian Neufeld*

1 - Optimizing Internet routing: a bilevel approach
Edoardo Amaldi

Internet routing optimization has been attracting considerable attention during the last decades. Although the ability of traffic flows to adapt their rate and fairly use all available resources is one of the Internet's pillars, this traffic characteristic, referred to as elasticity, has not yet been fully considered in the optimization literature. We present a new approach to network routing with elastic demands, where the interaction between the network operator and the congestion control scheme is modeled as a Stackelberg game, whose equilibrium can be computed by solving a bilevel optimization problem involving a fairness measure. After discussing structural properties and complexity issues, we describe single-level mixed-integer programming formulations and approximations for two fairness measures. Then we report some results obtained with exact and heuristic methods, which illustrate shortcomings of standard approaches neglecting the bilevel nature of Internet routing.

Thursday, 14:15-15:30

■ TD-01

Thursday, 14:15-15:30 - POT/006/H

Scheduling in Logistics

Stream: Project Management and Scheduling
Invited session
Chair: *Lennart Zey*

1 - Constraint Programming and Column Generation for Solving the Winter Runway Scheduling Problem at Airports
Maximilian Pohl, Christian Artigues, Rainer Kolisch

We address the runway scheduling problem under consideration of winter operations. During snowfall, runways have to be temporarily closed in order to clear them from snow, ice and slush. We propose an integrated optimization model to simultaneously plan snow removal for multiple runways and to assign runways and starting and landing times to aircraft. We present a time-discrete model formulation using clique inequalities, which builds up on Avella et al. (2017). We propose an exact solution methodology which combines a Constraint Programming heuristic with a Column Generation approach. An enhanced time-discretization method is used to balance model size and solution quality. We apply our algorithm to solve real-world data from Munich International Airport to optimality. We show that our method outperforms time-continuous formulations for large instances and if non-linear cost functions are considered.

2 - Levelling crane workload in multi-yard rail-road container terminals
Christian Pfeiffer, Malte Fliedner, Arne Schulz

In modern rail-road container terminals, container transshipment between trains and trucks is carried out by large gantry cranes that span over rail tracks and road lanes. Prior optimization approaches have mainly focused on the short term scheduling of these crucial transshipment resources. In this work we focus on a midterm planning level that assigns inbound trains to yard tracks, such that trains can be timely serviced by yard resources. This planning task is especially crucial in larger terminal settings which comprise more than a single yard, which is increasingly typical in growing intermodal networks. We describe the planning situation that we encountered at a large rail-road terminal in Germany and propose a mixed-integer model formulation that captures the core of the decision problem. We further carry out a complexity analysis of problem variants and develop a heuristic solution procedure in a simulated annealing framework based on these structural insights. The approach is tested in a comprehensive computational study, that demonstrates the viability of the approach to solve instances of real-world size.

3 - Twin-crane scheduling with a dedicated handshake area during seaside workload peaks
Lennart Zey, Dirk Briskorn, Nils Boysen

In this talk we consider a container transport scheduling problem for two twin-cranes that serve a storage block. Containers enter and leave the block at the seaside access point, resembling e.g. the ongoing (un-)loading of a vessel. The storage block is divided into two halves by a handshake bay and each of the cranes exclusively serves one of the sides. Whenever a container needs to be transported across that bay on its way to its final destination, it first is stored in one of multiple, capacitated storage slots within the handshake bay by one crane before afterwards the transport is completed by the respective other crane. We detail the precedence relations arising from stacking containers on top of each other and present multiple branch-and-bound approaches allowing to obtain minimum makespan schedules. Finally we provide some managerial impact on where to position the handshake area.

■ TD-02

Thursday, 14:15-15:30 - POT/051/H

Shipping Logistics

Stream: Logistics and Freight Transportation
Invited session
Chair: *Kevin Tierney*

1 - Liner shipping disruption management in practice: Generating recovery plans for vessels and cargo

David Franz Koza, David Pisinger, Grzegorz Siekaniec, Emil Sokoler

In large liner shipping networks, several hundred container vessels operate 24/7, following planned routes and timetables. These networks constantly face unexpected disruptions of varying magnitude. Among the most common reasons are bad weather, port congestions, labour strikes or equipment breakdowns at ports or on vessels. Disruptions may result in delayed vessels, temporarily disabled vessels, reduced port productivity, and port closures. Due to the cargo-driven connectivity of liner shipping networks, even a single delayed vessel can create ripple effects that affect multiple other vessels.

Resolving disruptions is a trade-off between minimizing operational vessel costs and port call costs on one side, and minimizing the impact on cargo, such as delays and re-routings, on the other side. One difficulty of finding a good trade-off arises from the fact that cargo related costs are largely not tangible or directly quantifiable, such as lost reputation and customer churn. Incomplete information during the planning of recovery plans adds another challenge: ports may reject a revised vessel schedule if no berthing window is available, resulting in multiple iterations of recovery planning.

We present a model and solution method that generates a set of recovery plans for the decision maker. We present preliminary results for test cases that were developed together with our industrial collaborator Maersk.

2 - Can autonomous vessels help short-sea shipping become more cost-efficient?

Kjetil Fagerholt, Mohamed Kais Msakni, Frank Meisel

Maritime transportation is witnessing an interesting opportunity by the introduction of autonomous vessels. With no crew on-board, autonomous vessels can be built with no deck house and no crew facilities, with reduced operational costs and more space for cargoes as a result. However, despite these obvious benefits, international regulations per today limit the introduction of fully autonomous vessels in international waters. Norway, as one of the largest shipping nations, is highly motivated by introducing autonomous vessels. In this regard, we study a real liner shipping network design problem for the transportation of containers between the European continent and Norway (i.e. short-sea shipping). We aim at determining the optimal fleet of vessels as well as their weekly routes. According to the current regulations, we assume that the network is based on mother and daughter vessels, where conventional mother vessels sail on a main route that links the European continent to one or several Norwegian transshipment ports, while autonomous daughter vessels with smaller capacities transport cargoes between these transshipment ports and other (smaller) ports located along the Norwegian coastline. We propose several mixed-integer programming models allowing for various network structures, as well as exact and heuristic solution methods for solving the different model variants. We generate a set of test instances based on the operations of a Norwegian container shipping operator and analyze the performance of the solution methods. More importantly, we analyze the economic impact from introducing autonomous vessels.

3 - Service independent liner shipping vessel routing

Daniel Wetzel, Kevin Tierney

Liner shipping networks are a central feature of modern supply chains that consist 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.

■ TD-03

Thursday, 14:15-15:30 - POT/081/H

Accounting

Stream: Revenue Management and Pricing
Invited session
Chair: *Georg Schneider*

1 - The Allocation of Responsibility between CEO and CFO for Financial Misreporting: Implications for Earnings Quality

Ulrich Schäfer, Viktoria Diser

Even though financial reporting primarily falls within the scope of the CFO responsibilities, there is considerable evidence for the CEO's influence on corporate misreporting. Regulatory initiatives such as the Sarbanes-Oxley Act of 2002 have therefore increased the CEO's responsibility in the preparation of financial statements and made CEOs partially accountable for misreporting by their subordinates. We analyze the allocation of responsibility between the CEO and the CFO in a theoretical model and highlight their implications for earnings quality. While increasing the CFO's responsibility generally improves earnings quality, assigning higher responsibility to the CEO may have detrimental effects. Our results show that higher CEO responsibility is particularly beneficial if the CEO has superior information about the CFO's (financial and non-financial) reporting objectives. Furthermore, the responsibilities of the CEO and the CFO are substitutive regulatory instruments: Regulators should only increase CEO responsibility if CFOs cannot be held responsible for their own misreporting decisions.

2 - Information Leaks and Voluntary Disclosure

Georg Schneider, Ulrich Schäfer, Michael Ebert

We study how the risk of information leakage affects the disclosure decisions of managers with unknown information endowment. If managers try to withhold proprietary information, investors may obtain a potentially noisy signal of this information via leaks. In this case, investors learn not only part of the information content but also realize that the manager has withheld information. The effects of such information leaks depend on their likelihood and precision. If leaks render the proprietary information with sufficient precision, a higher likelihood of leakage impedes voluntary disclosure. However, if leaks are imprecise, the model predicts that a higher likelihood of information leaks leads to more voluntary disclosure. For intermediate levels of precision, we find a non-monotonic effect. We conclude that the additional trans- parency established by a higher likelihood of information leakage fosters voluntary disclosures only if investors have difficulties interpreting the economic consequences of the leaked information. Such a situation is most likely the case in industries with complex business models and innovative products. Our findings may be useful ex- plaining mixed empirical evidence on voluntary disclosure and the availability of additional information sources.

3 - Tax avoidance and social control

Markus Diller, Johannes Lorenz

We present a model in which heterogenous, risk-averse agents can use either (legal) tax optimisation or (illegal) tax evasion to reduce their tax burden (earnings). Using exponential utility functions we find that the decision between optimisation and evasion does not depend on individual risk aversion or income. We use an agent-based simulation to incorporate social network effects to our analytical model. Using parameters that resemble the current situation in Germany, we find that legal optimisation is almost never beneficial compared to illegal tax evasion. Increasing audit rates may, however, change this relation. Honest behaviour is best promoted by strong social control. Imposing a fixed rather than linear penalty on tax evasion may help to prevent the spread of tax evasion otherwise associated with increasing tax rates.

■ TD-04

Thursday, 14:15-15:30 - POT/106/U

Advances in linear models

Stream: Control Theory and Continuous Optimization
Invited session
Chair: *Fränk Plein*

1 - Optimizing Large-Scale Block Diagonal LPs by Using Parallel Interior-Point Methods

Nils-Christian Kempke, Daniel Rehfeldt, Thorsten Koch, Ambros Gleixner

The current shift of energy systems in several European countries towards sustainable, renewable technologies comes with a massive decentralization and a concomitant increase in the size of realistic energy models. In addition, when dealing with uncertainty and in integrating large shares of renewable energies, energy system models require a detailed implementation of the underlying electricity system. Against this backdrop the project BEAM-ME has been launched to develop methods for solving currently intractable energy optimization problems. These models are encoded as large-scale linear programs (LPs) and exhibit a block-diagonal structure with both linking constraints and linking variables. For solving these problems we have adapted and enhanced the parallel interior-point solver PIPS-IPM, which was originally created for stochastic programs with block-angular structure. One of the enhancements that will be covered in this talk is the design and implementation of highly parallel presolving techniques. We will present the new extended version of PIPS-IPM with which we were able to solve problems with more than 250 million variables and constraints in a few minutes. We are going to show results of our implementation on several real-world energy system problems, solved by using the supercomputers of JSC (Juelich) and HLRS (Stuttgart) as well as the impact of our presolving routines on the solution time.

2 - A Steepest Feasible Direction Extension of the Simplex method.

Biressaw Wolde, Torbjörn Larsson

We present a feasible direction approach for general linear programming. It can be embedded in the framework of the simplex method, although it works with non-edge feasible directions. The principle used for choosing the feasible direction is the same as that of the steepest edge entering variable criterion in the simplex method, but in our method the directions of movement are not restricted to edges of the feasible polyhedron. The feasible direction used is therefore the steepest in the space of all (both basic and non-basic) variables, or an approximation thereof. Given a basic feasible solution, the problem of finding a (near) steepest feasible direction can be stated as a strictly convex quadratic program in the space of the non-basic variables and with only non-negativity restrictions. The direction found corresponds to a non-negative linear combination of the non-basic variables. In order to remain in the framework of the simplex method, this direction is converted into an auxiliary non-basic column, known as an external column.

Our feasible direction approach allows many computational strategies. First, one may choose how frequently external columns are created. Second, one may choose how accurately the direction-finding quadratic program is solved, that is, how good approximations of the steepest feasible directions that are used. Near-steepest directions can be obtained from low-dimensional restrictions of the direction-finding quadratic program or by the use of approximate algorithms for solving this program. Furthermore, we show that the direction-finding quadratic program can be solved by a column generation type method, which employs the same pricing problem as the simplex method but with a modified dual solution. We present encouraging computational results from preliminary experiments.

3 - There's No Free Lunch: On the Hardness of Choosing a Correct Big-M in Bilevel Optimization

Fränk Plein, Thomas Kleinert, Martine Labbé, Martin Schmidt

One of the most frequently used approaches to solve linear bilevel optimization problems consists in replacing the lower-level problem with its Karush-Kuhn-Tucker (KKT) conditions and by reformulating the KKT complementarity conditions using techniques from mixed-integer linear optimization. The latter step requires to determine some big-M constant in order to bound the lower level's dual feasible set such that no bilevel-optimal solution is cut off. In practice, heuristics are often used to find a big-M although it is known that these approaches may fail. In this talk, we consider the hardness of two proxies for the above mentioned concept of a bilevel-correct big-M. First, we prove that verifying that a given big-M does not cut off any feasible vertex of the lower level's dual polyhedron cannot be done in polynomial time unless P=NP. Second, we show that verifying that a given big-M does not cut off any optimal point of the lower level's dual problem is as hard as solving the original bilevel problem.

■ TD-05

Thursday, 14:15-15:30 - POT/112/H

Multimodal transportation

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Joachim R. Daduna*

1 - Journey Duration Comparison of a Planned Ropeway for Public Transportation with Existing Underground and Tram Lines

Marc Gennat

In Europe ropeways in public transport (PT) are often discussed in the recent years. Easy installations above existing infrastructure and streets, short dispatch periods, linear distance between the stations are advantages, to name a few. Thus, a lot of cities are planning such installations or further investigations on ropeways. Generally speaking, there are two goals for additional installations (Taylor 2015). First one is to minimize the car traffic by improving the PT system. This results in a change of the so called modal split. The second goal is to connect new traffic sources to the existing network. The in Europe planned ropeways for PT are always implemented in cities with existing PT systems and the goal is predominantly minimizing the car traffic. Thus, a lot of ropeway planning occur in cities with severe congestion problems to overcome the environmental and health issues, e.g. nitrogen dioxide pollutions, and to improve the personal living conditions.

To reassess the effect of ropeways on the wanted mode shift towards the PT sector, this additional installation has to be compared to the already operating lines of subway, trams and busses in the area studied. The comparison should be done with respect to the installation costs, the operational costs, and the journey duration (Mandl 1980, et. al.). In this contribution the latter is investigated, because the duration has a direct and most significant impact on the mode choice. The term duration of a journey has to be understood as the actual origin-to-destination time including all walking legs, travel and waiting times, which could be minimized by frequent departing gondolas.

A planned detachable gondola ropeway next to Frankfurter Ring in Munich is investigated. Hereby, the journey duration of ropeways is methodical introduced. Moreover, the connectivity between high-volume transportation systems as underground trains and frequent departing systems as ropeways with detachable gondolas is further examined. Also the car traffic congestion situation in the northern Munich area was measured by computing the duration in traffic-times provided by Google in a 10-minute-period from September to December 2018. Congestions also affect the travel times of public busses, which have to share the traffic lines with individual transport vehicles.

The journey duration between ten sources and destinations in the northern part of Munich with its 45 different routes is computed for the existing Underground and tram system, taking into account the delay of busses on shared traffic lines due to congestion. The same journey duration matrix is computed with the planned detachable gondola ropeway and its four stations. The comparison of both travel journey matrices shows advantages and disadvantages of ropeways in PT in the investigated case of the planned Munich ropeway. The conclusion discusses a generalization of the results for similar planned installations of ropeways.

2 - Modeling Intermodality to Improve Rural Accessibility

Laura Frank, Nicolas Dirks, Grit Walther

In rural areas, low population density and long travel distances provide major challenges for the public transportation system. As a result, public transportation in rural area is often characterized by low accessibility as well as long waiting and travel times despite high efforts and

costs. In order to improve rural transportation systems, public decision makers intent to implement alternative on-demand mobility modes. Herein, new intermodal travel itineraries with transfers at mobility hubs may enable faster public connections and thereby strengthen public transportation. Due to the high inherent complexity of intermodal connections, an appropriate planning tool is required that provides intuitive and communicable decisions for public decision makers.

Against this background, we present a decision support tool for the design of rural transportation systems based on mobility hubs and intermodal travel itineraries. As objectives, we aim at minimizing overall travel time as well as overall access to social opportunities. We decide on locations of mobility hubs where new mobility modes are offered in addition to existing public transportation modes. We model intermodal travel itineraries by considering transfers between different mobility modes at mobility hubs. Further, we present a procedure to reduce complexity of intermodal travel itineraries. Herein, we eliminate redundant itineraries due to upper bounds on travel time, mobility modes and transfers as well as dominated itineraries in terms of both required mobility hub installations and travel time.

Within an agile development process in close cooperation with public decision makers, we apply our approach to a real-world case study to validate our model, obtain results for public decision makers and gain general managerial insights. A-priori, an analysis of current travel volumes and current travel times highlights weaknesses of the existing public transportation system. Based on the two objective functions, we then obtain optimal locations for mobility hubs as well as suggestions for novel intermodal connections. First results promise significant potentials to reduce travel times as well as to improve access to social opportunities for rural inhabitants.

3 - Integrating autonomous vehicles to design innovative public transport services in rural areas
Joachim R. Daduna

In Germany, as well as in many European countries, people's mobility in rural areas is currently characterized to a significant extent by the use of private cars, while public transport plays a minor role. This situation is not preferable, in particular because of environmental considerations. However, this may be explained on the basis of the financial conditions and the resulting inadequate public transport services. But the increasing expansion of digitization and vehicle technology innovations (for example, autonomous driving), shows new approaches for service design in rural areas. The emphasis here is on a quasi-individualization of public mobility (e.g., through robotaxis, car-sharing and car-riding services) as well as the use of autonomously driving mini and midi buses with different operating concepts. This has far-reaching impacts on planning as well as monitoring and control of operations, but also on the internal and external information management. Thus, multimodal processes must be designed, which include not only timetable-based but also on-demand services. This concerns both the case of later intended trips and the case of current trips. This means that the planning processes as well as the provision of information at all levels must be largely in real time. Regarding the service structures, two areas need to be differentiated. First, it is the organization of collection and distribution trips from the rural area to link these to regional lines. Up to now, commuters are in the foreground, but this is not particularly preferable. Of importance is also the accessibility of higher-level centers for all groups of people who, for various reasons, have no access to traditional private transport, that is to say, to ensure basic mobility for the rural population. The second part concerns the provision of improved local and, to a lesser extent, regional mobility for the local population. This will lead to a reduction in car ownership, which is currently the highest in rural areas, with positive cost effects for the households concerned, but also regarding environmental aspects. Overall, a significant improvement in mobility also leads to an increase in the attractiveness of rural areas. Possible changes that will arise in transport services in rural areas will be shown, especially with regard to the use of multilevel structured multimodal trips in public transport. The objective here is to enable, as far as possible, a direct source-destination link, whereby the quasi-individual public transport systems serve as an essential basis. In this context, however, it is also necessary to build up suitable information and communication structures in order to provide comprehensive and real-time interlinking between public transport companies and customers. The main objective here is to exploit previously unachieved customer potential through a significant increase of the service level (within a politically predefined financial scope).

■ TD-06

Thursday, 14:15-15:30 - POT/151/H

Programming approaches for transmission networks

Stream: Energy and Environment
Invited session
Chair: *Dominik Möst*

1 - Combinatorial Reverse Auction to coordinate Transmission and Generation Assets in Brazil: Conceptual proposal based on Integer Programming
Laura Silva Granada, Fernanda Nakano Kazama, Paulo Correia

The Brazilian electric sector established a new regulatory framework in 2004, which altered among others, the trade regulations of the unbundled electric market. Nowadays, auctions are the main mechanism for contracting generation and transmission assets, guaranteeing the expansion of both generation facilities and transmission capacity. However, the mismatch between the start-up date of generation assets and transmission assets resulted in economic and energy inefficiencies. Since 2013, generation assets, already built and authorized to operate, were unable to connect into the basic network due to the absence of bids in the auctions of transmission assets. Therefore, 17000 GWh of power were not generated because of 15221 km of transmission lines unbuilt. In this context, a new combinatorial auction format that coordinates the generation/transmission assets promoting low tariffs is proposed. The conceptual proposal was divided into two bidding round: simultaneous clock and combinatorial first price sealed. The Winner Determination Problem could be reduced to treatable instances by identifying packages that allow the participants to express their economic synergy considering the computational capabilities.

2 - Semidefinite programming approach to Optimal Power Flow with FACTS devices
Bartosz Filipecki, Christoph Helmberg

Producing accurate and secure solutions to the Optimal Power Flow problem becomes increasingly important due to rising demand and share of renewable energy sources. To address this, we consider an Optimal Power Flow model with additional decision variables associated with line switching and FACTS devices, such as phase-shifting transformers (PSTs) or thyristor-controlled series capacitors (TCSCs). We show, how a Lasserre hierarchy can be applied to this model to obtain a semidefinite programming relaxation. Finally, we provide results of numerical experiments on this relaxation.

■ TD-07

Thursday, 14:15-15:30 - POT/251/H

Modelling for Logistics with Technical Constraints

Stream: OR in Engineering
Invited session
Chair: *Tim Müller*

1 - Optimal product portfolio design by means of semi-infinite programming
Helene Krieg, Jan Schwientek, Dimitri Nowak, Karl-Heinz Küfer

The design of a product portfolio is one of the most important issues a company has to deal with: It is the task of deciding which and how many products to produce. On the one hand, it is desirable to satisfy the demands of all potential customers. In the pump industry, for example, customers' needs in fluid transport tasks have to be met. On the other hand, it is economically advantageous to keep the number of products in the portfolio small. Using the example of pumps again, the smaller the number of differently sized pumps, the lower are the maintenance and storage costs for the company. Customer demands usually consist of an operation range, based on which a suitable product is chosen from the portfolio. Yet, there is uncertainty in the customer

specification, as the later use of the equipment might be subject to changes. Hence, an optimal product portfolio ideally consists of products that operate not alone in the customer specified set of operation points but in some larger set containing them. From the mathematical perspective, optimal product portfolio design was introduced in literature as a linear optimization problem with binary decision variables. In this problem, products are defined by a finite set of discrete-valued attributes and the portfolio should satisfy a finite number of customer demands. However, in several technical contexts, the products are machines which have continuous ranges of operation points. Thus, products can be identified with geometrical objects defined by continuous decision variables: the set of operation points at which they can be operated. To take uncertainty in customer demands into account, we further extend the problem by requiring that the objects do not cover finitely many but a compact, infinite set of operation points. As an objective, the product portfolio should cover each operation point in this set with high efficiency. All in all, we define a continuous set covering problem. Another reformulation results in a semi-infinite optimization problem (SIP). Unfortunately, the lower level problem of this SIP is neither smooth nor convex. Therefore, we present a method that solves a sequence of successively improved finite, nonlinear approximating problems. The approach uses adaptive discretization of the infinite index set of SIP and thereby keeps the problem size efficiently small. Furthermore, the non-smooth constraint function is approximated by a two-fold entropic smoothing function. The method is shown to converge under harmless requirements on the update of the discretization- and smoothing-based approximating problems and a worst-case convergence rate is given. Our numerical examples based on the application of optimal pump portfolio design show further that the worst case typically does not occur.

2 - Assessing and Optimizing the Resilience of Water Distribution Systems Using Graph Theoretic Metrics
Imke-Sophie Lorenz, Lena Charlotte Altherr, Peter Pelz

Water suppliers are faced with the great challenge of achieving high-quality and, at the same time, low-cost water supply. In practice, one is interested in the most cost-effective maintenance measures and/or capacity adaptations of existing water distribution systems (WDS). Since climatic and demographic influences will pose further challenges in the future, recently also the resilience of WDS, i.e. their capability to withstand and recover from disturbances, has been addressed. To assess the resilience of a WDS, different graph-theoretic approaches exist, cf. Shin et al. (2018) or Meng et al. (2018). Next to general metrics characterizing the network topology, such as average path length or central point dominance, also hydraulic and technical restrictions have to be taken into account, which are generally non-linear. In this work, we assess the resilience of an exemplary water distribution network of a major German city, and propose measures for increasing its resilience, e.g. by adding additional pipes or replacing existing ones by ones with adapted capacity. Bibliography: Shin, Sangmin et al. 2018. "A Systematic Review of Quantitative Resilience Measures for Water Infrastructure Systems." Water (Switzerland) 10(2): 1-25. Meng, Fanlin et al. 2018. "Topological Attributes of Network Resilience: A Study in Water Distribution Systems." Water Research 143: 376-86.

■ TD-08

Thursday, 14:15-15:30 - POT/351/H

Collaborative Vehicle Routing

Stream: Logistics and Freight Transportation
Invited session
Chair: *Jan Fabian Ehmke*

1 - Winner-takes-all-effects in collaborative vehicle routing
Margaretha Gansterer, Richard Hartl, Evgeny Gladun

Competitive markets, increased fuel costs, and underutilized vehicle fleets are characteristics that currently define the logistics sector. Given an increasing pressure to act economically and ecologically efficient, mechanisms that help to benefit from idle capacities are on the rise. In the Sharing Economy, collaborative usage is typically organized through platforms that facilitate the exchange of goods or services. Our study examines collaborative pickup and delivery problems, where carriers exchange customer requests. The aim is to quantify the potential of horizontal collaborations comparing centralized and decentralized frameworks. We confirm expected cost savings of 20-30% in a centralized setting. Unfortunately, these high collaborative gains typically come at the cost of an uneven customer distribution, which is known to be one of the main barriers of horizontal collaborations. However, we observe that this uneven distribution, or winner-takes-all-effect, strongly depends on the collaboration setting and the selected exchange mechanism. We show how to efficiently include constraints that prevent this effect and elaborate on settings where such constraints are not necessary.

2 - The Traveling Salesman Problem with Drone Re-Supply
Michael Dienstknecht, Nils Boysen, Dirk Briskorn

In this research, a novel problem setting concerning home delivery is considered. With steadily growing population density and increasingly congested streets in our cities on the one hand and a highly competitive market in e-commerce with the requirement of 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 cooperative approach with a single capacitated truck being re-supplied by 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 (e.g. fuel and driver's pay) and waiting (e.g. driver's pay), each drone flight is charged with a cost (e.g. for energy), 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 mixed-integer program and a non-exact decomposition approach is developed. A comparison of the novel concept with the traditional one (without drone re-supply) is provided.

3 - Analysis of re-optimization possibilities in dynamic routing of P/D vehicles
Milorad Vidovic, Nenad Bjelic, Drazen Popovic, Branislava Ratkovic

New opportunities and potentials for increased collaboration in logistics sector based on advanced optimization and modelling approaches and ICT advances, pose new challenges in the logistics and transportation systems' design, planning and operation. In that sense, vehicles' routes optimization, that has been attracting the attention of both, academics and practitioners, for more than 50 years, due to recent advances offer additional opportunities arising from real-time data availability. Although the dynamic routing as a concept exists in different forms almost three decades, re-routing of vehicles and network nodes reassignments almost was not possible until recently, when, due to ICT advances, become new option for additional savings and service level improving. Routing plan modification may be done periodically, based on certain data changes, for example on new user request appearance, or permanently throughout the vehicles working period, where set of solutions are memorized and checked on data change. In this paper we consider pick-up or delivery only vehicle routes where a set of requests should be transported to/from depot, which is both originating and ending network node. Pick-up or delivery process dynamic is assumed to be consequence of a demand quantity changes at user nodes, as well as new requests appearance/cancelation after initial routes determination, i.e. during the routes realization. The idea is to analyze pick-up or delivery only transport network served by fleet of vehicles with capacity constraints, in which central dispatcher possesses real-time information about new requests, customer demands status, and the vehicles status. The objective is to re-optimize current set of vehicle routes by reassigning user nodes because of changed demand, and inserting or rejecting new users. It is worth to be noted here, that the one of the most important questions here is related to defining reassignment and routes re-optimization strategies, i.e., when to modify vehicle routes. If routes changes at the beginning, only after few demand changes, while the vehicle capacities are still close to planned route's demand, its modification may cause negative effects on total routes length or execution time. Similarly, late modification may cause lowering of service quality. From there, this research should consider not only reassignment and re-optimization algorithms, but also mentioned strategies. Performances of the proposed approach, as well as the effects of the routes re-optimization and nodes re-assignments strategies are tested on set of numerical examples. Since the real time information about the user

nodes and vehicles status, obtained during the observed period, cause rapid increase of computational complexity, solution approach is based on metaheuristic algorithms.

■ TD-09

Thursday, 14:15-15:30 - POT/361/H

Human Aspects in Production Systems

Stream: Production and Operations Management
Invited session
Chair: *Simon Emde*

1 - Adapted Master Production Scheduling: Analysis on the impact of relevant social Performance Indicators from the GRI standard

Marco Trost, Thorsten Claus, Frank Herrmann

The sustainable development of processes is currently an important topic in industry and science. Various interest groups and other factors like resource shortages or a lack of skilled workers drive this trend. In the area of Production and Operation Management, the integration of sustainable aspects is also becoming more and more important. However, mainly ecological aspects are considered. Thus, this contribution expands the previous research by the integration of social aspects. For this, we limit our research to the Master Production Scheduling as part of operational production planning. In the context of sustainability, the Global Reporting Initiative (GRI) Standard has established itself for companies and other organisations to report on their sustainability activities. It is the first and most widely adopted global standards for sustainability reporting. The aim of this standard is to measure the sustainable performance and in this way, sustainability activities can be oriented to specific performance indicators. Accordingly, the GRI standard enables concrete initiatives to improve social, environmental and economic conditions for everyone. The modular standard comprises 36 standard modules. For this paper, the 19 social modules were analysed and relevant indicators that could be influenced by the Master Production Scheduling were identified. One of the important indicators from the GRI standard for our research question is the use of employees, measured in terms of hiring and employee turnover. The long-term employee commitment and thus low fluctuation will become a competitive advantage in the future, which is enhanced by the demographic change and the lack of skilled workers. In order to integrate these aspects based on the GRI standard, the classic formulation of Master Production Scheduling is extended. For this a control of the employee utilization within concrete utilization intervals as well as dependent processing times due to different exhaustion effects were integrated. Additionally, in order to take into account the requirements of a flexible production and to model the use of employees, aspects of personnel requirements planning are considered as well, which enable the build-up and reduction of capacity. As a result, social and economic consequences of related production scenarios are presented. In this context, a conflict of targets arises especially with macroeconomic fluctuations. On the one hand, shortages and inventories should be avoided from an economic point of view. On the other hand, a low and constant work intensity as well as a constant number of staff should be preferred for long-term employee commitment. Accordingly, the ability of the model to examine these questions, which will become more and more important for industrial enterprises in the future, becomes clear. Furthermore, it can be seen that it is possible to improve social aspects by adapted production planning without neglecting economic targets.

2 - Competence Management in Operation Research - A structured Literature Review

Patricia Heuser, Peter Letmathe, Thomas Vossen

Digitalization, globalization and demographic change reshape the way we work today. Current developments are characterized by an aging workforce, while production processes get increasingly interconnected and atomized. As a consequence, required employee skills change and traditional competencies loose value. Thus, a variety of new challenges arises and organizations need to integrate an effective management of employee skill and firm competencies into their strategic and operational management to stay competitive. To address this need, we aim to provide a state-of-the-art overview of research related to competence management in the field of operations research and we reveal avenues for further research. For this purpose, we use the term competence management as an umbrella term to integrate different quantitative approaches in this field, ranging from learning and skill portfolios, to qualifications and competencies. The structured literature review includes articles published between 1998 and 2018 in nine renowned OR and OM journals (Journal of Operational Research, International Journal of Production Research, International Journal of Production Economics, Management Science, Operations Research, Omega, Journal of Operations Management, Production and Operations Management and Manufacturing and Service Operations Management). From approximately 2398 articles, relevant research papers are extracted and clustered according to topic and methods. Finally, research gaps and areas for further research are derived.

3 - Loading tow trains ergonomically for just-in-time part supply

Simon Emde, Heiko Diefenbach, Christoph Glock

Faced with an aging workforce, many manufacturing companies consider alleviating the ergonomic strain of material handling on their workers increasingly important. This is one of the reasons why frequent small-lot deliveries of parts to the assembly stations on the shop floor via small electric delivery vehicles - so-called tow trains - have become widespread in many industries. Deploying tow trains, however, does not automatically ease the ergonomic burden on logistics workers, but requires careful stowage planning. We consider the following optimization problem. Given a set of bins of differing weight to be carried by tow train to a given set of stations on the shop floor, where should each bin be stowed on the tow train such that it can be unloaded efficiently from an economic perspective while also minimizing the ergonomic strain during loading and unloading? We investigate the physiological stress of handling bins on different levels of a tow train wagon by applying an established ergonomic evaluation method from the human factors engineering literature. We model the ensuing optimization problem as a special type of assignment problem and propose suitable exact and heuristic solution methods. In a computational study, our approaches are shown to perform well, delivering optimal solutions for instances of realistic size within fractions of a second in many cases. We show that optimal stowage plans can significantly ease the physiological burden on the workforce without compromising economic efficiency. We also derive some insights into the ideal layout of the tow train from an ergonomics perspective.

■ TD-10

Thursday, 14:15-15:30 - ZEU/114/H

Road Transportation

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Tim Zeitz*

1 - Spacing of intersections in hierarchical road networks

Masashi Miyagawa

This paper presents an analytical model for examining the spacing of intersections that connect different levels of roads in a hierarchical network. An analytical expression for the average travel time is obtained for a grid road network with two road types: minor and major roads. The travel time is defined as the sum of the free travel time and the delay at intersections. The analytical expression gives basic properties of the tradeoff between the travel time on minor and major roads. The optimal pattern of intersections that minimizes the average travel time is then obtained. The result demonstrates how the road length, the intersection delay, the travel speed, and the size of the city affect the optimal pattern. The model is also applied to the road network of Tokyo. The proposed model explicitly considers the tradeoff between the accessibility to higher level roads and the delay at intersections, and is useful for hierarchical road network design.

2 - An Econometric Analysis of the Determinants of Passenger Vehicle Sales in Germany

Hendrik Schmitz, Yu Zeng, Reinhard Madlener

Since the 20th Century, the automobile industry has become one of the pivot industries around the globe and has expanded prosperously. In the past ten years, however, the car industry faced new challenges and went through a series of troubles. Germany is known as one of the biggest automotive manufacturers in the world, accounting for more than 20% of all newly registered automobiles in the EU.

The estimation of automobile sales has been one of the most popular fields for econometric studies since the 1980s. Previous research on this topic has mainly focused on the correlation between automobile demand and economic indicators. Several studies have been conducted in this direction, using different econometric techniques. Research on the correlation between car sales, car features and government incentives remains relatively scarce. Specific research involving both economic and technical indicators on automobile demand, as done in our study, is still rare. Additionally, we focus on the differences and commonalities between distinct segments of the automobile market. The purpose of this study is to determine the main variables that had an impact on the sales of passenger vehicles in Germany.

In this study, we collect 2008-2016 monthly data of new registration vehicles to estimate the automobile demand in Germany. The possible indicators are divided into three groups, namely product-related variables, macroeconomic variables and government incentives. As our method, we select a multiple linear regression model with the monthly sales of vehicles as the explained variable. All passenger vehicles are divided into 9 segments according to their size and utilities. For each segment, a separate model is established, in order to uncover whether the specific predictors change over distinct car segments.

When we examine the total passenger vehicle market, we find that GDP and government incentives are significant predictors on the macroeconomic level, while price, gasoline consumption, quality and facelift of vehicles affect the automobile demand on the microeconomic level. As we turn to different car segments, one noticeable common feature among distinct segments is the high significance of the quality variable: vehicles with better quality performance are expected to have a higher sales volume in all car segments. One interesting finding is that the influence of the price variables on car demand vary from different segments: for mini cars, small cars and SUVs, prices are negatively correlated with sales, as expected. For large and sports cars, on the contrary, higher prices may lead to more sales; for medium, executive, luxury cars and MPVs, the price variables are no significant indicators for car demand. Accordingly, the demand for new passenger cars is found to be price-inelastic in most car segments. Our results have implications for car manufacturers and policy makers aiming at influencing the volume and structure of the car market in Germany.

3 - Space-efficient, Fast and Exact Routing in Time-dependent Road Networks

Tim Zeitz, *Dorothea Wagner*

Routing through road networks is an important component in many modern mobility applications. Road networks can be modeled as directed weighted graphs where nodes are road intersections and edges are streets. Edge weights represent the time it takes to traverse the corresponding road segment. The best route through the network can then be determined by calculating the shortest path between two nodes. This simple model has proven to achieve quite good results for practical applications. Assuming that the traversal times of road segments stay constant is not very realistic though. Traffic fluctuates over the course of a day and so do the times it takes to traverse road segments. Most of these fluctuations occur in recurring patterns. We can account for these patterns by modeling travel times as time-dependent functions which yield different travel times over the course of the day. This enables better routing and more accurate travel time predictions.

Beside a realistic model, it is also important that routing queries can be answered fast. Hierarchical speed-up techniques have proven to be a successful approach to accelerate shortest-path queries on road networks. One particularly successful example for this approach which also has been generalized to time-dependent routing are Contraction Hierarchies. The key ingredient of hierarchical speed-up techniques are shortcut arcs which are inserted into the network during preprocessing. During query time, shortcuts can be used to skip over unimportant parts of the network. While hierarchical speed-up techniques for time-dependent networks still achieve good query times, they often suffer from high memory consumption on modern production-grade instances. The travel time functions of shortcuts aggregate the complexity of all travel time functions in the paths they represent. Many approaches mitigate this problem through approximation by trading the exactness of queries against acceptable memory consumption.

We introduce Time-dependent Customizable Contraction Hierarchies. Instead of explicitly storing shortcut travel time functions, we augment shortcuts only with information for fast unpacking. Typically, Customizable Contraction Hierarchies require even more memory than Contraction Hierarchies. Despite this, our approach requires 30 times less memory than an exact time-dependent Contraction Hierarchy on our largest test graph. Through careful engineering and algorithmic improvements over previous work on approximate time-dependent Contraction Hierarchies by Batz et al., we achieve exact queries with running times competitive to exact time-dependent Contraction Hierarchies. Additionally, our approach allows updating the metric within a few minutes on modern production-grade continental sized instances.

■ TD-11

Thursday, 14:15-15:30 - ZEU/118/H

Safe & Secure Routing

Stream: Logistics and Freight Transportation
Invited session

Chair: *Adria Soriano*

1 - A mathheuristic framework for path inconsistency in routing

Philipp E.H. Salzmann, *Margaretha Gansterer*, *Karl Doerner*

We present a column generation-based framework for a variety of path inconsistency problems in the field of cash-in-transit routing. The framework can be used in an exact and or mathheuristic manner depending on the size of the instances. It is built around an adapted version of classical labelling and heuristic clustering and routing approaches. We observe an increase in solution quality on artificial instances and are able to solve real world instances efficiently. Additionally, the framework is applied to problems with alternative inconsistency definitions. We elaborate on validity and differences in costs for cash-in transot operations. It is shown that some of these inconsistency concepts are quite restrictive with regard to the application area and can be relaxed without compromising the integrity of the definition. This relaxation increases the number of possible solutions and decreases the costs significantly. The adaptations to the models and the algorithm performances are assessed on artificial and real world instances.

2 - Metaheuristics for the multi-objective and periodic node, edge, arc routing problem considering costs and route inconsistency

Georg Erwin Adrian Fröhlich, *Karl Doerner*, *Margaretha Gansterer*

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. Three approaches are taken. For the first and second approach the MO-P-NEARP is converted to a VRP-like problem on a directed simple graph and a directed multigraph respectively. For the third the MO-P-NEARP is not converted and instead the original graph network is used. The motivation for converting the MO-P-NEARP lies in VRPs already being extensively studied and having very competitive methods. However, in the multi-objective case creating all relevant paths, for guaranteeing the optimal solution regarding inconsistency on the conversion to also be optimal for the original problem, might not be feasible due to memory and might make the methods less effective. Therefore, the two graph types are used. The directed simple graph consists just out of the shortest paths, whereas the directed multigraph consists out of the top-k-shortest paths with a certain diversity amongst them. Not converting the MO-P-NEARP and using the original graph network instead for the third approach is motivated by the hope of possibly exploiting sparsity and finding more diversified solutions regarding inconsistency. In all cases three different multi-objective frameworks - multi-directional local search (MDLS), epsilon-constraint heuristic (ECH), and epsilon-box-splitting heuristic (EBSH) - are used sharing an underlying adaptive large neighborhood search (ALNS). For the first two approaches, the ALNS is tested for the single objective version with respect to costs on several benchmark sets (BHW, CBMix, DI-NEARP, MGGDB) and delivers results close to the best published ones. For both graph types, the multi-objective frameworks MDLS, ECH, and EBSH are compared on the MGGDB instances and some real-world instances based on Vienna. Benefits of using a multigraph can be seen for some instance types.

3 - Graph networks with alternative paths for the vehicle routing problem with arrival time diversification

Adria Soriano, Thibaut Vidal, Margaretha Gansterer, Karl Doerner

Regarding the transportation of valuables, also known as cash-in-transit (CIT) transportation, efficiency and security issues play a key role in the design of routes by companies. While efficiency relies on cost minimization, security is addressed by reduction of the risk of assault to a vehicle. This reduction can be achieved by designing unpredictable routes .In line with this, the vehicle routing problem with time spread constraints (VRPTS) defines a problem where a set of customers must be visited every day over a planning period, with the main restriction that there must be a minimum difference in the time of visit of a customer on each day. This generates unpredictable routing plans by spreading the arrival times to a customer, which also forces to use different sequences of visits and therefore different paths. This problem has received very little attention in literature. Besides, the problem has been only approached from a simple graph perspective. However, for certain problems like the one at hand, the use of optimal paths can make some good customer sequences infeasible due to arriving too early at a customer, thus leading to higher total costs. In such settings, the use of an alternative suboptimal path might be beneficial for the overall solution. Therefore, for a problem like the VRPTS, is interesting to consider the possibility of a vehicle taking a suboptimal alternative path to arrive to the next customer at a more suitable time. Furthermore, considering alternative paths helps on the goal of generating unpredictable routing patterns. In our study, we evaluate the influence of considering these broader graph networks for the VRPTS, by comparing them with the simple graph results. We develop an ALNS algorithm, coupled with the use of penalty functions, to tackle all possible graph considerations. We obtain results for existing and new sets of instances.

■ TD-13

Thursday, 14:15-15:30 - ZEU/147/Z

Operational Planning and Stochastic Simulation II

Stream: Simulation and Statistical Modelling
Invited session
Chair: *Catherine Cleophas*

1 - How to improve measuring techniques for the cumulative elevation gain upon road cycling

Maren Martens

In order to optimally prepare for competitions athletes gather as much data about their training units as possible. For cyclists, interesting figures are, e.g., the distance covered, the average and the maximum of speed, cadence, heart rate, and power output as well as the cumulative elevation gain. However, measuring devices do not always work reliably for all these factors. While factors like distance, speed, and cadence can be metered trustworthily with the help of magnets, which are attached directly to the bicycles, the metering of other factors still has room for improvement regarding accuracy and trustworthiness.

Here, we consider the cumulative elevation gain, the measurement of which is done by either GPS or barometric pressure nowadays. Therefore, it is dependent of steady connections to satellites (measurement by GPS) or steady changes in the barometric pressure. For the barometric pressure, however, it can happen that it varies merely due to weather changes or the time of the day. It is not surprising that for the same routes different measuring devices deliver quite different quantities for the elevation gain - not only depending on whether they measure by GPS or by barometric pressure. We present ideas on how to support measuring devices to deliver more reliable quantities for the elevation gain by using statistics and mathematical methods.

2 - Deterministic and Stochastic Simulation: A combined approach to Time Table Analysis

Stefan Wolfgang Pickl, Gonzalo Barbeito, Maximilian Moll, Wolfgang Bein

Timetabling is a very important topic in public transportation with the size of urban population continuously increasing. However, straigthforward calculcations of departure and arrival times through travel distances is usually not sufficient, since there is a variety of external factors that can have significant impact. This observation leads to an important OR problem: the routing of passengers in a transportation network, and how the introduction of stochastic behavior makes the system deviate from the ideal on which timetables are planned. The latter results in delays and unreachable transfers for passengers, which should be avoided or at least minimized. We present here deterministic and stochastic simulation approaches to this problem and their comparative analysis. The simulation of deterministic behavior is used to learn the explicit time tables, while that of the stochastic behavior emulates real-world schedule deviations. The stochastic behavior follows a sensible logic, where certain variables influence others, defining an implicit correlation network, e.g. different weather conditions affect number of passengers and trains' travel times. While each simulation on its own can be interesting, it is through their combination and comparison that new insights can be gained.

3 - MetaSimLab: A Laboratory for the Automated Calibration and Validation of Simulations

Catherine Cleophas, Anas Elhag

When employing simulation modeling to support decisions, modelers have to validate that the simulation's output matches empirical observations. Agent-based simulations, in particular, frequently include parameters that are not empirically observable. Modeling unobservables, e.g., as underlying human decision making, creates the problem of calibrating parameter values to produce valid outputs. We present a computational framework to evaluate the interplay of simulation models, calibration techniques, and validation approaches. By letting modelers code parameter requirements, the framework supports automated processes for calibration and validation independently of simulation domain knowledge. We exemplify these concepts through a computational study applying hyperheuristics for automated calibration.

■ TD-14

Thursday, 14:15-15:30 - ZEU/148/U

Dynamic Network Flows

Stream: Game Theory and Experimental Economics
Invited session
Chair: *Veerle Timmermans*

1 - Nash Flows Over Time with Spillback

Leon Sering, Laura Vargas Koch

Modeling traffic in road networks is a widely studied but challenging problem, especially under the assumption that drivers act selfishly. A common approach used in simulation software is the deterministic queuing model, for which the structure of dynamic equilibria has been studied extensively in the last couple of years. The basic idea is to model traffic by a continuous flow that travels over time from a source to a sink through a network, in which the arcs are endowed with transit times and capacities. Whenever the flow rate exceeds the capacity a queue builds up and the infinitesimally small flow particles wait in line in front of the bottleneck. Since the queues have no physical dimension, it was not possible, until now, to represent spillback in this model. This was a big drawback, since spillback can be regularly observed in real traffic situations and has a huge impact on travel times in highly congested regions. We extend the deterministic queuing model by introducing a storage capacity that bounds the total amount of flow on each arc. If an arc gets full, the inflow capacity is reduced to the current outflow rate, which can cause queues on previous arcs and blockages of intersections, i.e., spillback. We carry over the main results of the original model to our generalization and characterize dynamic equilibria, called Nash flows over time, by sequences of particular static flows, we call spillback thin flows. Furthermore, we give a constructive proof for the existence of dynamic equilibria, which suggests an algorithm for their computation. This solves an open problem stated by Koch and Skutella in 2010.

2 - On the Price of Anarchy for Flows over Time

Tim Oosterwijk, José Correa, Andres Cristi

Dynamic network flows, or network flows over time, constitute an important model for real-world situations where steady states are unusual, such as urban traffic and the Internet. These applications immediately raise the issue of analyzing dynamic network flows from a game-theoretic perspective. In this paper we study dynamic equilibria in the deterministic fluid queuing model in single-source single-sink networks, arguably the most basic model for flows over time. Here,

we are given a directed graph where each edge e has a positive capacity and a non-negative delay. A total amount of flow has to travel from the source s to the sink t, where flow departs from s at a given network inflow rate. If the inflow rate into an edge exceeds its capacity, a queue builds up, which empties at capacity rate. A particle entering an edge first encounters the queue and then travels along the edge. In the last decade we have witnessed significant developments in the theoretical understanding of the model. In particular, the structure of a dynamic equilibrium is known in which every particle selfishly chooses its shortest route. However, several fundamental questions remain open. One of the most prominent ones concerns the Price of Anarchy, measured as the worst case ratio between the minimum time required to route a given amount of flow from the source to the sink, and the time a dynamic equilibrium takes to perform the same task. Our main result states that if we could reduce the inflow of the network in a dynamic equilibrium, then the Price of Anarchy is exactly e/(e 1) = 1.582. This significantly extends a result by Bhaskar, Fleischer, and Anshelevich (SODA 2011). The proof proceeds in three steps. First we establish that the difference between the makespan of the equilibrium and the optimal flow is upper bounded by the overall sum of the queues at equilibrium divided by its inflow. This follows from the linear program that computes the optimal solution, combined with the equilibrium conditions stating that particles are routed through currently shortest paths. Second we establish a formula for computing this sum of the queues at equilibrium in terms of the derivatives of the dynamic equilibrium (thin flows). Finally the formula can be used to upper bound the sum of the queues at equilibrium by an appropriately small constant times the product of the inflow and the makespan of the equilibrium. Furthermore, our methods allow to determine that the Price of Anarchy in parallel-link networks is exactly 4/3. Finally, we argue that if a certain very natural monotonicity conjecture holds, the Price of Anarchy in the general case is exactly e/(e 1). Note that the missing case left by our main result is when the inflow rate of the equilibrium exceeds the inflow rate of the optimal flow. Intuitively, this case is easier. Indeed, for the theorem to hold in general it is enough to prove that by decreasing the inflow the makespan of the equilibrium increases.

3 - Termination Time of IDE Flows in Single Sink Networks
Lukas Graf, *Tobias Harks*, *Leon Sering*

In "Dynamic Flows with Adaptive Route Choice" (IPCO 2019) we introduced the notion of an instantaneous dynamic equilibrium (IDE) for dynamic network flows, requiring that for any positive inflow into an edge, this edge must lie on a currently shortest path towards the sink. Hereby, the current path length (or instantaneous travel time) is defined as the sum of the physical travel times and the current waiting times in queues. It was shown that, given a single sink network and bounded finitely lasting inflow functions, IDE flows always terminate within finite time, that is, after finite time all flow particles have reached the sink.

A natural question is to establish quantitative bounds on the termination time. We will provide an upper bound on the termination time which is polynomial in the total inflow volume and the sum of all edge travel times. We complement this upper bound by deriving a superlinear lower bound that grows with the total inflow volume times the logarithm of the sum of all edge travel times.

■ TD-15

Thursday, 14:15-15:30 - ZEU/160/H

Polyhedral Studies: Results and Applications

Stream: Discrete and Integer Optimization
Invited session
Chair: *Daniel Schmidt*

1 - Flow-based extended formulations for feasible traffic light controls
Maximilian Merkert, *Gennadiy Averkov*, *Do Duc Le*, *Sebastian Sager*

We study polyhedra that arise in the context of centralized optimization of traffic-light controlled intersections. Traffic light controls have to fulfill certain requirements in order to be reasonable or even legal such as minimum green and red phases or minimum and maximum cycle times of individual traffic lights, leading to extensions of min-up/min-down polytopes. Other constraints may affect several traffic lights at a given intersection simultaneously. Incorporating these rules vastly increases the computational difficulty of the overall MINLP formulation. We demonstrate that many natural requirements can be implemented by finite automata - enabling flow-based extended formulations of the corresponding 0-1 polytope. These also allow us to recover the complete description of min-up/min-down polytopes that is known from the context of unit commitment problems. Moreover, we discuss computational experiments on the impact of our extended formulations.

2 - Classifying partition based Chvátal-Gomory cuts for the Steiner tree problem
Daniel Schmidt, *Daniela Gaul*

It is well-known that k-partition inequalities are facet defining for the polyhedra of various network design problems. Furthermore, these inequalities can be derived as (0,1/m)-Chvátal-Gomory cuts, where m is a natural number that depends on k. Recently, the interest in these inequalities has sparked again, mostly through works by Agarwal and others. We consider the special case of the Steiner tree problem and classify k-partition inequalities based on the structure of the partitions. We analyze the strength of these inequalities and show that other inequalities can be derived as (0, 1/m)-Chvátal-Gomory cuts as well.

Joint work with Daniela Gaul.

■ TD-16

Thursday, 14:15-15:30 - ZEU/250/Z

Business Analytics

Stream: Business Analytics, Artificial Intelligence and Forecasting
Invited session
Chair: *Fabien Tricoire*

1 - Related Search Recommendations via NLP Methods and Networks
Robert Scheidweiler, *Stefan Dresselhaus*, *Michael Bastubbe*

In this talk we show how to compute related search recommendations for our website users. First, we describe empirical results of a search query analysis. Then, we report on our approach for building the mechanism: We combine so-called word embeddings, a technique that maps words/phrases/sentences in a vector space, e.g. via neural networks, with a specially designed network arising from our search queries. By exploiting the resulting graph, we are able to give good recommendations even if we encounter queries or query histories for the first time. Finally, we discuss some of the practical issues arising, e.g. how to deal with misspellings or how to perform evaluations.

2 - Machine learning-based queuing model regression - example selection, feature engineering and the role of traffic intensity
Roland Braune

The subject of this contribution is the performance prediction of queuing models based on advanced (multiple) regression techniques. The main motivation for this kind of approach is the mathematical intractability of queuing systems that are either non-Markovian in their nature or exhibit properties that render an exact analysis very difficult or even impossible. Examples include queues with general or degenerate arrival or service time distributions, non-homogeneous arrival processes, transient behavior and queuing networks with limited waiting space at nodes. The absence of closed-form expressions for the computation of performance measures makes it necessary to resort to stochastic simulation. Besides the effort required to implement such a model, its run-time may become the primary issue, particularly when used in a simulation-based optimization framework, as it is not uncommon in manufacturing and service operations management. "Learning" a regression model for the queuing system under consideration and then using it as a surrogate model for its simulation counterpart can therefore lead to considerable time savings during the run of the optimization algorithm.

The scientific literature on this specific scope of regression-based learning is surprisingly scarce. Only a few papers explicitly address this issue, albeit under quite specific scenarios. The goal of the contribution at hand is an in-depth regression analysis of various different

types of queuing systems, including queuing networks that violate conditions of Jackson, BCMP and Kelly networks. Performance measures of interest include the average number of customers in the system, the mean waiting and sojourn time, and various quantities derived from the probability distribution of waiting (or sojourn) times, like percentiles.

The first part of the study shows the validity of the approach, based on queuing models for which closed-form analytical solutions exist. It turns out that "non-linear" regression techniques, in particular support vector regression (SVR) and kernel ridge regression (KRR) are able to achieve almost perfect fits. The introduction of non-linear combinations of simple features like the arrival/service rates and the number of servers appears to be indispensable nevertheless. Training example selection via traffic intensity is compared to a purely random one. The experimental coverage is then successfully extended towards queuing networks of different kinds. Finally, potential and immediate application scenarios in ongoing projects, such as the optimization of a flexible manufacturing system and a public transport network, are sketched.

■ TD-17

Thursday, 14:15-15:30 - ZEU/255/Z

Recent Advances in Multi-Objective Optimization

Stream: Decision Theory and Multiple Criteria Decision Making
Invited session
Chair: *Sophie Parragh*

1 - The Bicriterion Maximum Flow Network Interdiction Problem in s-t-Planar Graphs

Luca Schäfer, Tobias Dietz, Marco Natale, Stefan Ruzika, Sven Krumke, Carlos M. Fonseca

In this presentation, we investigate the bicriterion maximum flow network interdiction problem in directed s-t-planar graphs. More specifically, we assume two different capacity functions on the set of arcs and two different "maximum flow players" to be given. Further, we allow B arcs to be interdicted by an interdictor. The task is to find the set of Pareto-optimal interdiction strategies, i.e., remove B arcs from the network, that minimize the maximum flow of both "maximum flow players" simultaneously. In practical applications one may want to determine the sensitivity of two different systems like transportation, water or power supply networks/systems against interruptions of roads.

It is well-known that there is a one-to-one correspondence between cuts in the directed s-t-planar graph, also called the primal graph, and paths in the corresponding dual graph. Further, the maximum flow equals the minimum cut, which in turn is equal to the shortest path in the dual. Consequently, the problem of finding the set of Pareto-optimal interdiction strategies in the primal graph is equivalent to finding the set of Pareto-optimal paths in the dual graph when B arcs are set to zero. We propose a labeling algorithm with a label selection strategy to iteratively compute the set of Pareto-optimal paths in the dual with B arcs set to zero. Therefore, we prove an upper bound on the number of labels at a node and show that the problem is NP-complete.

This research was partially supported by the Bundesministerium für Bildung und Forschung (BMBF) under Grant No. 13N14561.

2 - A comparison of lower bound set algorithms for multi-objective branch-and-bound

Duleabom An, Markus Sinnl, Fabien Tricoire, Sophie Parragh

We investigate multi-objective optimisation problems where the multiple objectives are conflicting. Since there is, in the general case, no solution which optimises all objectives simultaneously, the aim is to obtain the Pareto optimal set. The branch-and-bound algorithm is one method that produces this set of solutions. To extend an existing bi-objective branch-and-bound to the three-dimensional case, finding lower bound sets is the first step. Since the computational effort spent obtaining lower bound sets represents a major portion of the whole effort, we investigate three different approaches. Those methods are based on a Benson's algorithm and its dual variant, on a dichotomic scheme, and on a parametric simplex for multi-objective problems. In this presentation, we compare the performance of all three algorithms by applying them to widely used benchmark problems (assignment problems, knapsack problems, mixed integer problems). Furthermore, we look into factors which influence the efficiency of each algorithm.

3 - Bi-objective facility location in the presence of uncertainty: An evaluation of stochastic and robust modeling approaches

Najmesadat Nazemi, Sophie Parragh, Walter Gutjahr

Multiple and often conflicting criteria need to be taken into account in real world problems. Moreover, due to dealing with data in a non-precise real world, considering uncertainty is of vital importance.

To cope with uncertainty in optimization problems, many different approaches have been presented in the literature. The most widely used ones are stochastic optimization including concepts such as the expected value, chance constraints or risk measure, and robust optimization, including prominent concepts such as minmax robustness or adaptive robust optimization.

This paper aims at investigating bi-objective modeling frameworks for an uncertain location-allocation model to design a humanitarian aid delivery network in disastrous situations. In order to find an efficient and reliable methodology to solve the problem, we consider slow-onset as well as sudden-onset disaster settings which differ in the sources of uncertainty. We use three different approaches to model uncertainty: scenario-based two-stage stochastic optimization, minmax robust optimization and adaptive robust optimization. To deal with the bi-objective nature of the problem, all three approaches are embedded into criterion space search methods, namely the well-known epsilon-constraint method and the recently introduced balanced box method.

We evaluate and compare the performance of the applied approaches on data sets derived from real world case studies.

■ TD-18

Thursday, 14:15-15:30 - ZEU/260/H

Demand side modelling

Stream: Energy and Environment
Invited session
Chair: *Dogan Keles*

1 - Agent-based Simulation of the Heating Market using the MCDA Method PROMETHEE

Beatriz Beyer, Lars-Peter Lauven, Jutta Geldermann

In Germany, 80 % of the heat demand is still covered by fossil fuels, which causes 40 % of all energy-related greenhouse gas emissions. About 70 % of its 20.7 million residential heating systems are older than 15 years and correspondingly energy inefficient. Landlords' and households' decisions for a heating system are cost-intensive and long-term investments and influence the sustainability of the market over a long time. In order to obtain deeper insights on the market dynamics for a more sustainable heating market, we developed an agent-based simulation model and applied it exemplarily to Hanover, a region and city in northwestern Germany. Different agents in the model represent various heating system owners and their dissimilar decision behavior. The agents differ in terms of their individual preferences, knowledge, heat demand, the age of the heating system and their ownership structure. To account for these characteristics and preferences we modeled the individual decision processes as multi-criteria decisions using the outranking method PROMETHEE (Preference ranking organization method for enrichment evaluation), programmed as a JAVA extension. Economic (total costs per year and fuel price uncertainties), environmental (greenhouse gas emissions), social (knowledge and experience), and technological (comfort of use and infrastructure) criteria were used for the multi-criteria decision process. With the combination of an agent-based simulation and multi-criteria decision processes of individual heating system owners, the possible effects of different legislations can be analyzed more closely. Different scenarios concerning price fluctuations, behavioral changes, and incentive programs are simulated. Thus, this agent-based simulation of the heating market allows for a better understanding of the interdependencies and potential developments of the market and can therefore be used as a decision support tool for the industry or policy makers.

2 - Choosing the right technologies for thermal and electrical power supply in office buildings

Volker Maag, Elisabeth Finhold, Lukas Romanowski

The energy supply system of an office building is a complex interaction of grid connections, generators, storages, distribution pipelines, heating and cooling surfaces and ventilation. One of the first steps of designing such a system is the technology decision for heating, cooling and electrical power supply. There is a wide range from grid connections, usage of solar energy, heat pumps to the burning of fossil fuel. The decision for one or a combination of these technologies is usually made in an early planning stage of the building where only basic data is available. The challenges when trying to make a well-founded decision is not only to estimate the investment cost but also the operational costs of so many technologies. Often the planer sticks to the simplest solution just because she or he is not familiar enough with the most interesting alternatives. The goal of our decision support tool is to motivate a higher investment with less fossil fuel consumption by showing its economically advantage: Not always but often enough there are solutions which will be amortized after some years because of their lower operational costs. Our tool consists of five components: • An appropriate building model, which does not need more data than available in an early planning stage. • An approach to estimate the demand of thermal and electrical energy based on a detailed simulation of a reference building and statistical models for transferring demands to the building to be constructed. • A framework to model and simulate generators and storages and their interaction. • Models for most common generators like heat pumps, combined heat and power plants, geothermal energy, photovoltaic, VRF-systems and boilers. • An UI frontend for comparing key performance indicators (investment, operational costs, etc.), calculating amortization times, and presenting the simulation details. • An administration tool for maintaining a database of components of different power levels for each supported generator type. The key design aspect for the modelling of the generators are the speed of the evaluation and restriction of model inputs to data available on technical data sheets of the components, since there may be many components to be considered. This leads to a rule based approach instead of a detailed description of the physical processes. The tool is successfully used in practice for the customer consulting at Goldbeck, a German construction company.

3 - Smart energy management systems to facilitate peer-to-peer energy trading

Lissy Langer, Thomas Volling

Germany is struggling to comply with its 2020 climate action goal to cut carbon emissions by 40% compared to 1990. Reducing emissions requires an increasing amount of renewable energy sources in the German energy mix. The efficiency and reliability of such an energy system will mostly depend on its ability to dynamically match local supply and demand in order to prevent expensive grid expansion. Home energy management systems could enable automated peer-to-peer trading on a decentralized market if they would be able to determine a reasonable price tag. In this dynamic stochastic environment, continuous learning and optimization will have to work hand-in-hand to support anticipatory in-house flow management as well as informed market price offerings. The approach is illustrated from a PV owner's perspective managing a heat pump as well as a thermal and a battery storage system, in addition to that she has to decide on her constant peer-to-peer customer tariff. The approach facilitates offline expert learning in a simulated setting and continuously adapts its function approximation via online learning.

Thursday, 15:45-17:00

■ TE-01

Thursday, 15:45-17:00 - POT/006/H

Hybrid Flow Shops and Job Shops

Stream: Project Management and Scheduling
Invited session
Chair: *Ina Kortemeier*

1 - Constructive heuristics in hybrid flow shop scheduling with unrelated machines and setup times

Andreas Hipp, Dimitri Felka, Jutta Geldermann

A hybrid flow shop system (HFS) consists of series of production stages with parallel machines on at least one stage. HFS is often found in industry environments such as semi-conductor production or chemical industry. In steel industry, the processing of sheets can be displayed by HFS. Sheets require special properties of the production system, e.g. different sheets which are processed in the same system lead to different sequence dependent machine setups. Furthermore, the processing times of sheets with similar characteristics can differ on each machine. To display this type of production system, we focus on a HFS with unrelated machines and anticipatory sequence-dependent setup times. The setups are characterized by different setup categories which group jobs into clusters. If two jobs of the same setup category are scheduled consecutively on the same machine, no setup procedure is required between them. As a result, the clustering of jobs regarding their setup can influence both, the performance of the whole system and the assignment of jobs to machines on each stage. Apart from that, we assume HFS with more than two stages to minimize makespan. In addition, a second objective function regarding setups is separately formulated which minimizes the number of setups in the schedule to illustrate the trade-off between setup-related expenses and production pace. Because the HFS scheduling problem with two stages and identical machines is already proved to be NP-hard by Gupta in 1988, we deal with a constructive heuristic, i.e. the well-performing heuristic of Fernandez-Viagas et al. (2018). This approach based on the algorithm of Nawaz, Enscore and Ham (NEH-algorithm) is modified and extended for the described layout as it is initially implemented for HFS with identical machines. In total, two heuristics are formulated, one for solving each of the two objective functions. Benchmarks provided by the Spanish research group Sistemas de Optimización Aplicata (SOA) for HFS with identical machines and setup times are adapted and conducted. Setup categories are determined by clustering setup times. All over, a testbed consisting of 960 instances is implemented. We investigate the trade-off between aiming at setup procedure-related and pace-related objectives in a HFS. It can be shown that having setup categories does not automatically lead to typical job batching in the resulting schedule for makespan minimization in HFS.

2 - Flexible job shop scheduling problems in the presence of a heterogeneous workforce

Dominik Kress, David Müller

We consider two variants of flexible job shop scheduling problems that incorporate heterogeneous machine operator qualifications by taking account of machine- and operator-dependent processing times. In the first setting, we incorporate sequence-dependent setup times, while the second setting does not take account of setup restrictions. We consider two objective functions: makespan minimization and minimization of the total tardiness. We then present exact and heuristic decomposition based solution approaches for both settings and assess the quality of our solution methods in an extensive computational study that is based on randomly generated as well as real-world problem instances.

3 - Dynamic Scheduling in a Job Shop Environment

Ina Kortemeier

Unconditional adherence to deadlines and accurate information on delivery dates are among the key criteria for modern production companies to successfully position themselves on the market. We therefore consider a flexible job shop scheduling problem with sequence dependent setup times (FJSP-SDST) and tardiness criteria. To solve the problem, it is necessary to assign each operation to a suitable machine on the one side, and on the other, to sequence the operations on the machines. Since in reality jobs usually arrive over time and are not known from the beginning, the problem is furthermore extended to a dynamic FJSP-SDST. In this research, we seek to find an efficient

way to view this problem as a rescheduling problem and thus solving a series of static problems over time. We describe a discrete event simulation model and a corresponding method for rescheduling.

■ TE-02

Thursday, 15:45-17:00 - POT/051/H

Scheduling & Dispatching

Stream: Logistics and Freight Transportation
Invited session
Chair: *Frank Meisel*

1 - A Polynomial Time Algorithm for a Truck Driver Scheduling Problem with Multiple Customer Time Windows and Two Types of Breaks
Alexander Kleff

Truck drivers have to abide by legal provisions regarding breaks in order to rest sufficiently. Such break rules need to be considered when the work of a driver is scheduled. Given a sequence of customers to be visited and some break rules, the truck driver scheduling problem is the problem of finding a feasible schedule such that each customer is visited in time, that is, within one of the customer's time windows, and the break rules are respected.

In this talk, we regard two types of breaks - a short meal break and a longer rest break. A break of either type becomes due when the driver has accumulated a certain driving time since the last break or when a certain time has elapsed since then. This truck driver scheduling problem arises both in the US and in the EU for a planning horizon of several days.

We present a polynomial time algorithm for this problem under the assumption that breaks are only taken at customers or other dedicated locations on the way. To the best of our knowledge, it is the first polynomial time algorithm for this problem.

2 - Predicting demand for road haulage with external data: a comparison of methods
Benedikt Sonnleitner, Christian Menden

Road haulage companies have to plan about one week in advance, which transport capacities they need. Therefore, dispatchers manually forecast the required trucks and drivers with by means of expert knowledge. However, the human experts underestimate or overestimate the requirements that arise. This leads to costs since short-term booking of freight capacity is expensive - just like booked but unused capacity. We develop a forecasting model that predicts demand on trucks based on a variety of external factors, such as weather, public holidays or macroeconomic indicators. In particular, we use various filter and wrapper methods in order to identify and select potential features. We then use those identified features to compare the performance of multivariate statistical methods and artificial neural networks. First results indicate that both methods improve the forecasts when comparing them to a baseline model.

3 - Interday Scheduling and Routing of Multi-Skilled Teams with Consistency Consideration and Intraday Rescheduling
Yulia Anoshkina, Frank Meisel

We consider a combined manpower scheduling and routing problem for performing spatially distributed jobs that demand one or more skilled workers. We investigate for example how the staffing can be updated for new jobs that occur within the planning horizon. We address this by approaching the problem from a multi-period perspective. More precisely, we propose a rolling horizon approach with different intraday rescheduling strategies and team consistency consideration. On this basis we develop linked mathematical optimization models for the interday and intraday re-planning. For solving large problem instances, we propose a fix-and-optimize heuristic. Our experiments analyze the effectiveness of the proposed approach and reveal the impact of integrating team consistency into manpower scheduling.

■ TE-04

Thursday, 15:45-17:00 - POT/106/U

Software Applications and Modelling Systems II

Stream: Software Applications and Modelling Systems
Invited session
Chair: *Viktoria Hauder*

1 - Solving Large-Scale GAMS Models on HPC platforms
Frederik Fiand, Michael Bussieck

Often large-scale optimization problems exhibit a certain problem structure that is usually not exploited by general purpose solvers but could in theory be utilized by (parallel) structure exploiting algorithms. A good example for such optimization problems are Energy System Models (ESM) like unit commitment, optimal power flow, and economic dispatch. Such models developed and maintained by (academic) research institutes, multi-national organizations, and commercial companies often evolved over time and represent sophisticated and intricate software systems. The modeled time horizon of ESMs can span decades and due to open markets for electricity these models cover bigger and bigger regions. Hence, ESMs tend to push the boundaries of available computational resources. In the last three years a multidisciplinary team of researchers from ZIB/TU Berlin/JSC/HLRS/GAMS/DLR investigated ways to handle linear programming based ESMs of exceptional size in a project named BEAM-ME with a strong focus on HPC algorithms (http://www.beam-me-projekt.de/beam-me/EN/Home/home_node.html). We will give an overview of the various activities in this project and emphasize on challenges related to migrating GAMS based ESMs to a high-performance computing environment.

2 - Real-time multi-criteria consumer credit offer optimization
Johannes Müller

Consider a client who wants to raise a car loan or mortgage. The bank wants to make a small number of attractive offers, which are likely accepted and profitable for the bank. The bank is also interested in managing its risk profile carefully.

We present a FICO analytic cloud based optimization solution that computes multiple optimized credit offers in real-time, while taking the clients or banks objectives, the banks rule based risk models, and additional mathematical constraints into account.

3 - What it takes to deploy Operations Research projects successfully into business applications
Jens Schulz

Digitalization, 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, 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? Many OR experts, solution developers and data scientists fail to execute the last mile - getting their work in the hands of business users. After all, it is the business experts who are making day-to-day decisions for the enterprise.

In this session, we will show how to successfully deploy analytic and optimization models with FICO Xpress. Xpress includes a web deployment platform, Xpress Insight, which enables solution developers, data scientists, and OR experts to rapidly develop and deploy applications. To unleash the full power of optimization, it needs to move out of the lab and into the operations of the business. In particular, we will present some success stories from our client base then showcase how an optimization app can be created via drag & drop within few minutes by using our latest product enhancement "View Designer".

■ TE-05

Thursday, 15:45-17:00 - POT/112/H

Carsharing

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Kevin Tierney*

1 - User-based relocation strategies in free-floating car sharing systems

Fabian Rüdel, Maximilian Schiffer, Grit Walther

Free-floating car sharing systems offer flexible mobility services, while lowering necessary parking spaces and reducing traffic congestion. However, spatial and temporal mismatches of supply and demand of rental cars require the relocation of cars to avoid low utilization of cars. As these relocation activities are a major cost factor in car-sharing fleets, operators discuss the potential of user-based relocation in which a user is given a discount to modify its rental request slightly. While the general concept of user-based relocation appears to be promising, no profound impact analysis exists so far.

Against this background, we introduce the Car Sharing Relocation Problem with Flexible Drop-Offs (CSRP-FDO) that optimizes the assignment of user-based relocation strategies in free-floating car sharing fleets. We analyze user-based relocation strategies which allow to modify the start time, the arrival time, the origin, or the destination of a customers' trip. We provide an integer program model formulation for the CSRP-FDO as well as a reformulation as a k-Disjoint Shortest Paths Problem and propose an exact algorithm to solve large-sized instances.

We present a real-world case study to analyze the impact of user-based relocation strategies. Our results show that the effectiveness depends on the implemented user-based relocation strategies. Temporal relocation strategies, i.e., modifying the start time or the arrival time yield only small improvements in additional covered rental requests or profit. Contrary, spatial relocation strategies, i.e., modifying the origin or the destination yield significant improvements, enabling a 40% increase in covered rental requests and a 10% increase in profit.

2 - Price list optimization in free floating carsharing

Christian Müller, Matthias Soppert, Jochen Gönsch, Claudius Steinhardt

Shared mobility providers offer short term rentals for cars or bicycles. Depending on the restrictions regarding a rental, shared mobility systems are classified as either station-based or free-floating systems. While station-based shared mobility systems require rentals to start and end at defined locations (stations), free-floating systems only require rentals to end within the operating area of the provider. A decisive aspect of free-floating shared mobility systems is the ever-changing spatial fleet distribution that is not subject to any station location as it is in station-based systems. Customers in free-floating shared mobility systems therefore check for available vehicles within the vicinity of their preferred rental start. In order to increase utilization and profitability in shared mobility systems, cost driven approaches like efficient relocation but also pricing driving methods that target both price and passive relocation come into operation. Pricing approaches in shared mobility systems either have a service or monetary objective. They can be differentiated into origin-, destination- and origin-destination oriented pricing schemes as well as static and dynamic approaches.

We contribute by proposing a price optimization approach for free-floating shared mobility systems that consider the effects of a certain walking distance and the zone area, with the zone being an appropriate part of the operating area. We derive profit maximizing origin-oriented prices in a static pricing setting. The static pricing problem is formulated as a Mixed Integer Linear Program that is based on a deterministic network flow formulation that maximizes the profit by choosing the best price out of a given price list for every period (30 minutes) and zone.

3 - An ADP approach for rebalancing free-floating vehicle sharing systems

Kevin Tierney, Frederik Schulte

Free-floating vehicle sharing (FFVS) systems enable customers to rent vehicles on a short term basis and flexibly leave them anywhere within a pre-defined service area within a city. The freedom these systems provide to customers is a major selling point, however it is also a drawback, as vehicles are often left in undesirable locations where they may not be effectively utilized. Thus, the vehicles of FFVS systems must be rebalanced to ensure customers can find vehicles near them. To this end, we propose an approach based on approximate dynamic programming that learns where vehicles are needed at various times of the day and uses a stochastic optimization model to send the vehicles to appropriate locations. We show experimental results indicating the effectiveness of our approach on an artificial benchmark of vehicle sharing instances.

■ TE-06

Thursday, 15:45-17:00 - POT/151/H

Industrial optimisation 2

Stream: Energy and Environment
Invited session
Chair: *Philipp Hauser*

1 - Optimal design and operation of renewable fuel supply chains

Michael Wolff, Tristan Becker, Grit Walther

The short- and long-term temporal and spatial volatile renewable energy generation by solar, wind and biomass is the major challenge for the design and operation of renewable energy systems and cross-sectoral supply chains. To balance supply and demand, efficient use of transmission, transport and storage of renewable energy is essential. Herein, gaseous or liquid fuels, i.e., fuels produced from renewable electricity, bio-based carbon feedstocks and CO2, can be used multifunctional as renewable high-density energy carrier, carbon source as well as long term energy storage in industry, the transport and the energy sector. Thus, renewable fuels could take a leading role in climate change mitigation. However, design and operation of supply chains for these renewable fuels is challenging due to the volatile feedstock supply. Against this background, we present a decision support system for renewable fuel supply chains explicitly incorporating temporal and spatial volatile renewable energy generation. We build upon a spatial and temporal explicit mixed integer linear programming (MILP) formulation for the optimal design and operation of supply chains. Herein, the objective is to maximize the net present value. Strategic decisions include multi-period investment decisions regarding facility locations, production technologies, plant and storage capacities, as well as decisions for the installation of the required transport infrastructure. Short term decisions include the operation and utilization rate of production, transport and storage technologies. Resource conversion as well as transport and storage processes are modeled using the State-Task Network representation. Since the simultaneous consideration of strategic and operational decisions in the model leads to a high number of time periods, a time decomposition approach is implemented. We apply the model to a European scale case study and discuss insights on the optimal design and operation of renewable fuel supply chains. Special focus is on the impact of operational aspects, e. g. part load operations and potential overcapacity of the production plants as well as different storage options, on the long-term net present value and the optimal design of the supply chain. Since the model formulation results in a mathematical programming problem with a high number of decision variables and constraints, trade-offs in spatial and temporal resolution are discussed.

2 - A hierarchical covering location model to determine the number and location of garbage stations -A case study in Minamata City, Kumamoto Prefecture-

Qiannan Zhuo, Koki Ogai, Ken-ichi Tanaka, Wanglin Yan

Minamata City, locates in Kumamoto Prefecture Kyushu Island, has a 25-year experience on applying household recycling. The residents need to sort the garbage from households into more than 20 categories before bringing it to garbage stations. For the complexity of its waste management system, this study takes Minamata City as an example to investigate the appropriate number and location of the household recyclable waste garbage stations with a hierarchical covering location model. Covering-type location models have been used widely in existing literature to optimize the facility number and location. In the proposed model, the demand nodes are the residential buildings, the data of candidate nodes for the garbage stations are made from current garbage stations and the real road data. The covering radii are calculated from the previous questionnaire survey. In 2016, a questionnaire survey targeted all Minamata households successfully collected 4,222 valid answers, which covered around 35% of all the Minamata households. A part of its result shows the distribution of satisfaction

degree changes depending on the access time to the garbage station. The longer it takes to the garbage station, the degree of satisfaction decreases. Thus, we set the relative benefit of the distance from each household to the closest garbage station as a step-like shape. By maximizing the sum of relative benefit of each demand, we calculate the optimal number and location of garbage stations. We compare the optimized facility number and location with the current ones from the residents' point of view. By enhancing the accessibility to the garbage stations, the optimized result becomes more convenient and effective for Minamata residents.

■ TE-07

Thursday, 15:45-17:00 - POT/251/H

OR for Construction and Production

Stream: OR in Engineering
Invited session
Chair: *Andreas Schmitt*

1 - Periodic Scheduling Tools for Robot Manufacturing Systems

Tobias Hofmann

The employment of industrial robot systems in the automotive industry noticeably changed the view of production plants and led to a tremendous increase in productivity. Nonetheless, rising technological complexity, the parallelization of production processes, as well as the crucial need for respecting specific safety issues pose new challenges for man and machine. Our goal is to develop algorithms, guidelines and tools that make the commissioning of industrial robot systems more dependable by verifying the programs of robots and logical controllers. This in particular includes optimizing the schedule of the robot systems in order to ensure desired period times as well as conflict free timetables already in the planning stage.

We investigate the applicability of the Periodic Event Scheduling Problem proposed by Serafini and Ukovich in 1989 in order to tackle this cycle time minimization problem. We establish a variant of the classical formulation in order to cover the special characteristics of the scenario. Beyond the modeling aspects, we discuss the problems computational complexity as well as polyhedral aspects of the mathematical formulation. Furthermore, we present developed software tools that support engineers and programmers throughout the comissioning of robot production systems. Finally, our computational results on real-world as well as designed data sets confirm the practical usability of the proposed approach.

2 - The Branch and Refine Algorithm for Time Dependent Discrete Optimization Problems

Fabian Gnegel, Armin Fügenschuh

One of the standard approaches for solving time-dependent discrete optimization problems (such as the travelling salesman problem with time windows (TSPTW) or the shortest path problem with time windows) is to derive a so called time-indexed formulation. If the problem has an underlying structure that can be described by a graph, the time-indexed formulation is usually based on a different, extended graph, commonly referred to as the time-expanded graph. The time-expanded graph can often be derived in such a way that all time constraints are incorporated in its topology, and therefore algorithms for the time-independent variants become applicable. However, the downside of this approach is, that the sets of vertices and arcs of the time expanded graph are much larger than the ones of the original graph. In recent works, however, it has been shown that for many practical applications a complete expansion, guaranteeing feasibility of all paths, is not necessary in order to find a proven optimal solution. The solution approaches usually iteratively refine the original graph and solve a relaxation of the time expanded formulation in each iteration. The refinement process can then be terminated if the optimal solution of the relaxation is time feasible. In this work we present new ideas, that allow for the propagation of information about the optimal solution of a coarser graph to a more refined graph and show how these can be used in iterative refinement algorithms. In particular for MILP based formulations we present a new algorithm that allows for the graph refinement to be carried out during the exploration of the branch-and-bound tree instead of restarting whenever the optimal solution was found to be infeasible. In order to demonstrate the practical relevance of this algorithm we present numerical results on its application to the TSPTW.

3 - Exploiting Partial Convexity of Pump Characteristics in Water Network Design

Andreas Schmitt, Marc Pfetsch

The design of water networks consists of selecting possible pipe connections and pumps to ensure a given water demand and minimizing investment and operating costs. This yields complex mixed-integer nonlinear programs. In particular, the modeling of variable speed pumps usually involves so-called characteristic diagrams, which are often approximated using degree two and three polynomials. This contributes, in large parts, to the non-convexity and nonlinearities of the problem.

This work investigates a reformulation of these characteristic diagrams, eliminating rotating speed variables and determining power usage in terms of volume flow and pressure increase. We characterize when this formulation is convex in the pressure variables. This structural observation is applied to design the water network of a high-rise building in which the piping is tree-shaped. For these problems, the volume flow can only attain finitely many values. We branch on these flow values, eliminating the non-convexities of the characteristic diagrams. Then we apply perspective cuts to strengthen the formulation. Numerical results demonstrate the advantage of the proposed approach.

■ TE-08

Thursday, 15:45-17:00 - POT/351/H

Location Planning

Stream: Logistics and Freight Transportation
Invited session
Chair: *Alf Kimms*

1 - On supply-driven location planning problems

Hannes Hahne, Thorsten Schmidt

So far, most of the location planning problems discussed in literature are demand-driven. It means that a set of facilities must be assigned to a set of allowed locations (e.g. modeled as a network) in order to completely satisfy the demands of a set of customer sites (Laporte, G. et. al. 2015, Hanne et. al. 2017). In order to differentiate between feasible solutions, an objective function (e.g. minimize transport distances) must be taken into account in most cases. Therefore, these problems are considered as optimization problems.

In this article, we present "real world" location planning problems that we have analyzed in the context of logistics optimization for renewable energy from biomass (e.g. Delzeit 2008, Unal et. al. 2011, De Meyer et al. 2015, Yuruk 2016, Silva et al. 2017), which leads us to expand the demand-driven approaches by a supply-driven one.

First, we describe the peculiarities of these problems verbal and show why they should be considered supply-driven. In addition, we give a more generic mathematical formulation that leads to a compact mixed integer linear problem (MILP) that covers these problems and emphases the logistics aspects in our research, especially the transport cost minimization. Second, we extract an integer linear problem (ILP) as a sub-problem of the original MILP, by reformulating some specific restrictions, which leads us to the core of our supply-driven idea. We further show that the relaxation of the sub-problem results in a polyhedron whose convex hull has unique properties compared to general integer problems . Based on these specific properties we provide an algorithm that solves the formulated sub-problem in an acceptable time. In addition, we give a proof that the algorithm is correct. Third, we present the assumptions and the structure behind a developed tool that is capable of creating thousands of varied sized problem instances for our MILP. Based on these instances, we provide a detailed statistical analysis that leads us to the conclusion that problem instances in range of "real world size" can be solved with acceptable efforts, using open source MILP-solvers (e.g. CBC, GLPK).

Finally, we summarize the benefits of our work and show why the formulation of the sub-problem and its solution might help to increase the transparency and therefore the acceptance of the MILP for any location planning process related to biomass-conversation plants in practice. Furthermore, we give an outlook how supply-driven approaches could be helpful beyond the renewable energy context.

2 - A Finite Dominating Set Approach for Planar p-Hub Location Problems
Thomas Ullmert, Andrea Maier

Research on Hub Location Problems (HLP) has become popular in the last 30 years. This is due to its various applications, e.g., in communication network design or airline routing problems. In the Planar p-Hub Location Problem (PpHLP), one has given a set of customers and demands between each pair of customers. The task is to locate p hubs in the plane and assign the customers to a hub, such that the total cost for transferring the demands between customers via the hubs is minimized. Thereby, it is assumed that direct connections between costumers are not allowed. In general, the PpHLP is NP-hard. Here, we present a Finite Dominating Set (FDS) approach to the problem equipped with a special distance function, a so-called symmetric gauge. We first note that if an assignment is known, the problem is equivalent to a p-Median Problem. Therefore, we develop an FDS based on geometric optimality conditions for the p-Median Problem, which is of polynomial size if p is fixed. We then elaborate on finding an assignment if a set of hubs is given. It turns out that some variants of the PpHLP are solvable in polynomial time for fixed p, whereas others remain NP-hard. For the hard problems, we propose heuristics to obtain the assignment and present promising results.

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3 - Solving a multiple allocation p-hub median problem with general non-decreasing piecewise-linear costs using Branch-and-Price
Marlon Gwiasda, Alf Kimms

Hub-and-Spoke Networks are widely used for large scale many-to-many transportation applications such as postal or parcel distribution, LTL transportation or passenger transportation. In Hub-and-Spoke Networks commodities are restricted to only pass through a subset of nodes called hubs. This reduces the number of used links and therefore also reduces network complexity. The possible consolidation of flows can lead to higher transportation volume resulting in for example cost degression effects (Economies of Scale) or even contrary increasing marginal costs caused by congestion effects (Diseconomies of Scale). Those cost curves can be modelled or at least approximated by general non-decreasing piecewise-linear cost functions. Our approach establishes p nodes to function as hubs. Commodities can only be consolidated at hubs or send directly from source to sink. There are no restrictions on the number of hubs a node can be connected to known as multiple allocation. Instead of choosing nodes or segments through one binary variable each our model chooses combinations of nodes or segments called patterns. Choosing patterns instead of single objects strengthens the LP bounds at the cost of many decision variables. The large number of patterns is tackled by a Branch-and-Price Algorithm that decomposes the problem and only generates a subset of all feasible patterns.

■ TE-09

Thursday, 15:45-17:00 - POT/361/H

Production Planning and Lot Sizing

Stream: Production and Operations Management
Invited session
Chair: *Matthias Gerhard Wichmann*

1 - Capacitated lot sizing for plastic blanks in automotive manufacturing integrating real-world requirements
Janis Sebastian Neufeld, Felix Jörg Schmidt, Tommy Schultz, Udo Buscher

Lot-sizing problems are of high relevance for many manufacturing companies, as they have a major impact on setup and inventory costs as well as various organizational implications. We discuss a practical capacitated lot-sizing problem, which arises in injection molding processes for plastic blanks at a large automotive manufacturer in Germany. 25 different product types have to be manufactured on 7 distinct machines, whereas each product type may be assigned to at least two of these machines. An additional challenge is that the following production processes use different shift models. Hence, the stages have to be decoupled by a buffer store, which has a limited capacity due to individual storage containers for each product type. For a successful application of the presented planning approach several real-world requirements have to be integrated, such as linked lot sizes, rejects as well as a limited worker and buffer capacity. A mixed integer programming model is proposed and tested for several instances from practice using CPLEX. It is proven to be able to find very good solutions within in a few minutes and can serve as helpful decision support. In addition to a considerable reduction of costs, the previously mostly manual planning process can be simplified significantly.

2 - Multi-commodity lot-sizing in chemical industry with supplier selection, storage selection and discounts
Thomas Kirschstein, Frank Meisel

Multi-commodity lot-sizing in chemical industry with supplier selection, storage selection and discounts

In this talk a sourcing problem of a chemical production facility is outlined. The production facility sources raw materials from a set of suppliers offering discounts. For storing raw materials, different storage facilities can be used with varying cost rates and capacities. We formulate the corresponding planning problem of selecting suppliers and storage locations as well as determining order quantities and transport flows under the discount schemes offered by the suppliers as a mixed-integer program for a discrete number of periods. For solving large problem instances, a variant of the kernel search heuristic is proposed and evaluated in a real world case study. The case study reveals that supplier selection and storage selection are highly interdependent decisions. By integrating both perspectives, significant savings can be generated. It turns out that typically a sole optimal supplier exists for each raw material. However, the selection of the optimal suppliers depends on both the prices offered by the suppliers as well as the associated logistical costs for transportation and stock-holding.

3 - Capacitated lot-sizing and scheduling with time-dependent energy prices and sequence-dependent, period-overlapping setups
Matthias Gerhard Wichmann, Christoph Johannes, Thomas Spengler

Against the background of an increasing awareness of sustainability, companies are driving numerous activities to strengthen sustainability in production processes. Besides several technical possibilities for a more sustainable production, one further possibility on the part of companies is to pay attention to such aspects in the production planning. Therefore, in order to improve the resource- and energy-efficiency, an increasing number of model formulations for resource- and energy-efficient production scheduling have been developed. Recent adjustments in the energy market because of the transformation to a more sustainable power generation will offer customers time-dependent energy prices in the future as an incentive for a supply-oriented energy demand and a new opportunity for reducing energy costs. Existing planning approaches such as the Energy-Oriented Lot-sizing and Scheduling Problem show the potential of the usage of time-dependent energy prices. However, these planning approaches are not suitable for an application in real world settings, based on their increasing solution time with higher number of products and periods. Therefore, in this contribution a new model formulation for the capacitated lot-sizing and scheduling problem with the consideration of time-dependent energy prices is presented. Within a theoretical comparison and a real world-oriented case study, considering a pre-crushing system for waste electrical equipment, the model formulation for the Energy-Oriented Lot-sizing and Scheduling Problem is evaluated compared to energy- and non-energy-oriented model formulations. This shows that the new model formulation outperforms the further investigated model formulations significantly in cost saving potential and partly in solution time and solvability.

■ TE-10

Thursday, 15:45-17:00 - ZEU/114/H

Midterm and Long-term Planning in Production Systems

Stream: Production and Operations Management
Invited session
Chair: *Katja Schimmelpfeng*

1 - A flexible shift system for a fully-continuous production division
Elisabeth Finhold, Tobias Fischer, Sandy Heydrich, Karl-Heinz Kuefer

Shift planning is a challenging task as it typically comes with a wide range of individual requirements. We show how we developed and evaluated a shift system for a fully-continuous production division that allows incorporating stand-by duties to cope with production-related fluctuations in personnel requirements. Besides the desired flexibility, strict requirements concerning weekend work were a particular challenge. We started by analyzing the relations between fundamental parameters of shift models like the number of shift groups, the weekend load, working hours and weekend shift size to balance out the desired but incompatible properties of the shift system. We also identified general properties of shift models that allow integrating standby duties in a way such that working a standby shift will only result in small changes to the overall plan while preserving the desired properties of shift sequences for all employees. Based on these preliminary considerations we developed an integer programming formulation to find a suitable base shift model. The resulting shift system is parametrized in the number of standbys. Finding suitable values is a multicriteria decision problem under uncertainty. To contrast the competing objectives like the proportion of additional demand covered, the frequency of standby shifts per worker or the associated costs, we used a simple simulation-based approach in which we evaluated several scenarios for additional personnel demand for all potential parameter values.

2 - Allocation and management of shared production buffers: Problem formulation and classification scheme
Nora Krippendorff, Christoph Schwindt

Buffer sharing may allow for a substantial increase in the system's throughput in comparison to buffers dedicated to specific item types. Since recent developments in smart intralogistics enable cost-effective material flows between machines and distributed buffers, exploiting the additional flexibility of shared production buffers has become a realistic option. In case of buffer sharing, the general buffer allocation problem consists in assigning a set of buffer slots to each item type of the production system. All buffer slots with the same allocation of item types form a buffer. Whereas the allocation problem for dedicated buffers received extensive attention in literature, the formation of shared buffers has only been investigated for special cases. Shared buffers give rise to a buffer management problem on deciding in which buffer slot to store and from which buffer slot to pick an item each time an item has been processed or is wanted for processing. A simple class of solutions to this problem are management rules based on partially ordered sets of buffer slots. For each item type, the respective order establishes precedence relations among the buffer slots. The buffer allocation problem and the buffer management problem are mutually linked and therefore should be treated jointly. Given some objective function to be optimized, the evaluation of a buffer allocation depends on the buffer management rule chosen, and the buffer management rule refers to a given buffer allocation. We introduce the combined buffer allocation and management problem as a bi-level optimization problem. For the combined problem, we propose a classification scheme serving to refer to special cases in a unifying compact way. The scheme comprises five fields characterizing the structure of the production system, the feasible assignments of buffer slots to item types, the distributions of interarrival and processing times, the feasible buffer management rules, and the objective function to be optimized for the considered problem. Furthermore, we explain how to represent buffer management rules in the transition graph of the system's throughput process. Finally, we discuss preliminary computational results obtained for a small Markovian flow line with a general buffer configuration and sketch first ideas for the solution of the combined buffer allocation and management problem.

3 - Long-term electricity production planning of a flexible biogas plant considering wear and tear
Katja Schimmelpfeng, Hendrik Butemann

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.

■ TE-11

Thursday, 15:45-17:00 - ZEU/118/H

Flow Shops

Stream: Project Management and Scheduling
Invited session
Chair: *Kathrin Maassen*

1 - A new speed-up procedure in the permutation flowshop scheduling problem
Victor Fernandez-Viagas, Jose M. Molina-Pariente, Jose M Framinan

The scheduling literature is abundant on approximate (i.e. not exact) methods for scheduling in a permutation flowshop layout, as this results in a NP-hard problem for the majority of objectives usually considered. Among these methods, some of the most efficient ones employ an insertion-type of neighbourhood to construct high-quality solutions, or to improve an existing solution via local search. It is not then surprising that using accelerations to speed up the computation of the objective function can greatly reduce the running time of these methods, since a good part of their computational effort is spent in the evaluation of the objective function for the different solutions tested. Undoubtedly, the best-known of these accelerations -employed for the makespan minimisation- is due to Taillard (1990), which is considered now to play a fundamental part in all state-of-the-art methods for makespan. These accelerations have been extended to other related problems, but they cannot be employed for the classical permutation flowshop problem if the objective is other than the makespan. For these objectives, other types of accelerations have been proposed, but they are not able to achieve a substantial reduction of the computational effort.

In this paper, we propose a new speed-up procedure for permutation flowshop scheduling using objectives related to completion times. We first present some theoretical insights based on the concept of critical path to show that only a fraction of the completion times of all jobs have to be re-computed when inserting a job into an existing sequence. We also provide an efficient way to compute the critical path (indeed Taillard's accelerations appear as a specific case of these results). The proposed accelerations are extensively tested for the following objective functions: total completion time; total tardiness; and total earliness and tardiness. The results show that the computational effort is reduced, on average, more than 50%, 60%, and 75% for total completion time, total tardiness, and total earliness and tardiness, respectively.

2 - Time-dependent emission minimization in sustainable flow shop scheduling
Sven Schulz, Florian Linß

Over the past decades, global warming and climate change have gained increasingly more public attention. It is generally accepted that the global warming is caused by greenhouse gas emissions, in particular the carbon dioxide produced by the combustion of fossil fuels. In 2016, the industrial sector consumed about 54% of the world's energy and is therefore responsible for a large proportion of global emissions. Currently, companies are mainly encouraged to save emissions through good will and image enhancement. But increasingly also taxes and related regulations are discussed to limit the carbon footprint. Consequently, ecological aspects, such as emissions, must also be integrated into operative planning in the future. In contrast to cost-intensive and time-consuming technical conversions, such planning approaches can be integrated quickly and inexpensively. This contribution considers a flow shop scheduling problem. There are already some articles concentrating on emissions in production scheduling. However, most of these works are limited to multiplying the energy consumption by a fixed value to calculate the emissions. These approaches therefore only minimize the energy demand. In reality, the amount of pollutants emitted strongly depends on the energy mix and thus on the respective time period the energy is used. For example, when there is a lot of wind and the sun is shining, there is a lot of renewable energy, which reduces emissions. In order to take this important connection into account during the planning phase, we propose a new multi-objective MIP formulation which considers time-depending carbon dioxide emissions. In

addition to emissions, the makespan is minimized as a second objective in order to produce not only sustainably but also efficiently. Since the two objectives are conflicting, there is not only an optimal solution but a multitude of pareto optimal solutions. Based on lexicographic solutions the optimal pareto front is determined using the epsilon constraint method. A computational study is carried out to analyze the influence of fluctuating emissions and different modes as well as to investigate the relationship between the two objectives. Therefore, real carbon dioxide data is used. On this basis, a sensitivity analysis is carried out to discuss the influence of larger and smaller fluctuations in caused emissions.

3 - Diversity of processing times in permutation flow shop scheduling problems

Kathrin Maassen, *Paz Perez Gonzalez*

Structuring processing times in static-deterministic permutation flow shop scheduling has been discussed in the literature several times. Depending on the given structure of processing times, a reduction to the easy solvable single machine layout, according to the objective function, is possible. Moreover, a specific structure of processing times is needed if layouts with a certain dominance behavior of machines are considered (in a nutshell, machine A dominates machine B if the minimum processing time on A is higher than the maximum processing time on B (dominance type II)). The examples show that the way of generating processing times and the corresponding structure is a key factor to discuss scheduling problems. The variability of processing times can be measured by the coefficient of variation and in this work it is denoted as diversity of processing times to distinguish from stochastic scheduling. To control diversity, we use the logarithmic normal (LogN) distribution, instead of the commonly used uniform distribution. Moreover, the classical permutation flow shop is considered and the objectives makespan and total completion time are discussed. Core idle time and core waiting time can be seen as indicators for efficient production systems because their minimization leads to high utilized machines and job flow. Therefore, core idle time and core waiting time and their behavior with respect to diversity are discussed as well. In this work, we first provide clear definitions and characteristics of diversity. Secondly, we examine the influence of LogN-distributed processing times on the chosen objective functions with different diversity levels. Complete enumeration is applied to provide not only one optimal solution but to also evaluate the whole range of solutions referring to different diversity levels.

■ TE-12

Thursday, 15:45-17:00 - ZEU/146/Z

Modeling

Stream: Optimization under Uncertainty
Invited session
Chair: *Marc Goerigk*

1 - Flexible capacity configuration with indivisible resources - a basic model for the uncertain demand case

Fereidoun Rashidi, *Ralf Gössinger*

Capacity as the maximum possible production output per period is generated by investments in non-consumable indivisible resources (e.g. worker, machine). For being able to adapt the effective capacity to fluctuating requirements, multiple resources with the same functionality can be used to build up the total capacity. In this case, flexibility builds on the possibilities of activating a certain number of resources and determining their degree of utilization. As soon as individual resources can be different in terms of cost and capacity amount (apart from their functionality), capacity configuration becomes a combinatorial problem. The involved decisions form a hierarchy: For setting up capacity, it has basically to be decided on the portfolio of resources subject to their indivisibility. Building on that, adaptation decisions on resource activation and utilization are to be taken subject to possible demand quantities. In the intended paper we consider the situation in which production is faced with stochastic demand and capacity can be generated by picking out one portfolio from a given set of alternative resource portfolios. Resources have the same quasi-infinite useful life (such that differences in investment costs can be neglected) and differ in their capacity, activation costs and utilization cost rate. Whilst utilization costs incurred with each capacity unit of a resource applied for demand fulfillment, activation costs are induced as soon as at least one capacity unit of the resource is utilized. Since we further assume that backordering and inventory holding are not possible, opportunity costs become relevant, too. Insufficient capacity (lost sales) is valuated with the price that would have been gained by first-best utilization, whereas idle capacity (slack) is valuated with the difference of prices attainable for first and second-best utilization. The capacity configuration problem has to be solved in such a way that the sum of expected costs is minimized. In order to inquire the structure of optimal solutions to this problem numerically, we develop a MILP model, conduct a full-factorial numerical study, and analyze relations between model input and output statistically.

2 - Model Formulations for the Stochastic Liner Shipping Fleet Repositioning Problem

Jana Ksciuk, *Stefan Kuhlemann*, *Kevin Tierney*, *Achim Koberstein*

The repositioning of vessels is a costly process for liner shipping companies. During repositioning, vessels are moved between services in a liner shipping network to adjust the network to changing macroeconomic conditions or varying customer demands. A deterministic model for the Liner Shipping Fleet Repositioning Problem (LSFRP) exists, but many input parameters to the LSFRP are uncertain. Assuming deterministic parameters could lead to extra costs when plans computed by the deterministic model are realized. To get more realistic repositioning plans, uncertainties regarding influences on the travel time or the number of available containers, must be considered. We present stochastic versions of existing node- and arc-flow based model formulations and evaluate them based on industrial data. Business insights related to the consideration of uncertainty during planning will be discussed. To assess the risk associated with a repositioning plan the conditional value-at-risk (CVaR) is added to the optimization model. This enables a decision-maker to state his or her willingness to take risk before the optimization process starts. As a result of the analysis we will show the benefits of applying stochastic optimization when generating repositioning plans.

3 - Production planning under demand uncertainty: a budgeted uncertainty approach

Pawel Zielinski, *Romain Guillaume*, *Adam Kasperski*

In the talk we focus on the tactical level of a capacitated production planning for the master production scheduling (MPS) under uncertainty. Namely, we deal with a version of the capacitated single-item lot sizing problem with backordering under uncertainty in the demand. We assume that its deterministic counterpart is polynomially solvable. We consider the interval uncertainty representation of uncertain cumulative demands, i.e. a closed interval is assigned to each cumulative demand, which means that its possible value will belong to the interval, but it is not possible to predict which one. Such uncertainty representation is more realistic than the interval uncertainty representation of demands in periods, that can lead to huge uncertainty over the planning horizon. We assume that the intervals have a symmetric form centered at the most likely values of uncertain cumulative demands, called the nominal ones. Thus the values of uncertain cumulative demands can deviate from their nominal ones by at most their maximal deviations prescribed. Furthermore, we control the amount of uncertainty allocated by an adversary to cumulative demands by an additional linear (budget) constraint. Such interval uncertainty representation with the budged constraint is called a budgeted uncertainty. We examine two its variants. The first one, the discrete budgeted uncertainty, in which it is assumed that at most a specified number of cumulative demands can deviate from their nominal values at the same time. The second variant, the continuous budgeted uncertainty, in which it is assumed that the sum of the deviations of cumulative demands from their nominal values, at the same time, is at most a provided upper bound on the total variability. In order to choose a robust production plan for the problem under consideration that hedges against the demand uncertainty, we adopt the well-known minmax criterion which is regarded as very risk averse and conservative. However, it turns out that under the budgeted uncertainty, assumed in our talk, one can flexibly control the level of conservativeness of resulting production plans and allow decision maker to take his/her attitude towards a risk into account while a plan is determined.

In this talk we show that evaluating the impact of uncertainty in the demand on a given production plan in terms of its cost under the discrete and continuous budgeted uncertainty can be done in polynomial time. Moreover, we propose polynomial and pseudopolynomial methods for determining a robust production plan, respectively, under the discrete and budgeted uncertainty - it is the main result.

■ TE-13

Thursday, 15:45-17:00 - ZEU/147/Z

Special Graph Structures

Stream: Graphs and Networks
Invited session
Chair: *Markus Sinnl*

1 - Exact Solutions for the Steiner Path Problem on Special Graph Classes

Jochen Rethmann, Frank Gurski, Stefan Hoffmann, Dominique Komander, Carolin Rehs, Egon Wanke

The Steiner path problem is a restriction of the well known Steiner tree problem such that the required terminal vertices lie on a path of minimum cost. While a Steiner tree always exists within connected graphs, it is not always possible to find a Steiner path. Despite this, one can ask for the Steiner path cover, i.e. a set of paths which contains all terminal vertices. We point out similarities and differences between both problems w.r.t. their time complexity restricted to special graph classes. Further, we show how a Steiner path cover of minimum cardinality for the disjoint union and join composition of two graphs can be computed from the corresponding values of the involved graphs. This allows us to compute a Steiner path cover of minimum cardinality for co-graphs in linear time. Moreover, we optimize the costs within a Steiner path cover for the disjoint union and join composition of two graphs by the costs of the involved graphs. This leads us to a linear time computation of a Steiner path cover of minimum costs and thus an optimal Steiner path, if it exists, for special co-graphs.

2 - Subset Sum Problems with Special Digraph Constraints

Frank Gurski, Dominique Komander, Carolin Rehs

The subset sum problem is one of the simplest and most fundamental NP-hard problems in combinatorial optimization. We consider two extensions of this problem: The subset sum problem with digraph constraint (SSG) and subset sum problem with weak digraph constraint (SSGW). In both problems there is given a digraph with sizes assigned to the vertices. Within SSG we want to find a subset of vertices whose total size does not exceed a given capacity and which contains a vertex if at least one of its predecessors is part of the solution. Within SSGW we want to find a subset of vertices whose total size does not exceed a given capacity and which contains a vertex if all its predecessors are part of the solution. SSG and SSGW have been introduced recently by Gourves et al. who studied their complexity for directed acyclic graphs and oriented trees. We show that both problems are NP-hard even on oriented co-graphs and minimal series-parallel digraphs. Further, we provide pseudo-polynomial solutions for SSG and SSGW with digraph constraints given by directed co-graphs and series-parallel digraphs.

3 - On algorithmic approaches for the S-labeling problem

Markus Sinnl

In this talk, we present algorithmic approaches for the recently introduced S-labeling problem, in which the nodes get labeled using labels from 1 to $|V|$ and for each edge the contribution to the objective function, called S-labeling number of the graph, is the minimum label of its end-nodes. The goal is to find a labeling with minimum value. The problem is NP-hard for planar subcubic graphs, although for many other graph classes the complexity status is still unknown.

We present different algorithmic approaches for tackling this problem: We develop an exact solution framework based on Mixed-Integer Programming (MIP) which is enhanced with valid inequalities, starting and primal heuristics and specialized branching rules. Moreover, we also present a dual-ascent-like heuristic, a Lagrangian heuristic and a constraint programming approach. Finally, we give, to the best of our knowledge, the first polynomial-time algorithm for the problem on complete n-ary trees as well as a closed formula for the S-labeling number for such trees.

■ TE-14

Thursday, 15:45-17:00 - ZEU/148/U

Game Theory and Experimental Economics I

Stream: Game Theory and Experimental Economics
Invited session
Chair: *Martin Bichler*

1 - Core-Stable Outcomes for Combinatorial Exchanges with Budget Constraints

Stefan Waldherr, Martin Bichler

Combinatorial exchanges allow buyers and sellers to specify package bids, i.e. a price is defined for a subset of the items for auction. The price is only valid for the entire package and the package is indivisible. Such types of markets have significant potential for the private and the public sector. Examples include day-ahead electricity markets, supply chain coordination and trading fishery access rights.

Buyers often face budget constraints that limit their bids, even though they have significantly higher value for packages. However, since these constraints can usually not be express in the exchange, this can lead to depressed bidding and inefficiencies even in the presence of non-strategic bidders.

We analyze pricing and different notions of stability in combinatorial exchanges where buyers have budget constraints. Our aim is welfare maximization subject to budget constraints and core-constraints in large non-convex markets. The computational complexity analysis yields that the allocation and pricing problems become $Sigma_2p$-hard with budget constraints by a reduction from the canonical $Sigma_2p$-complete problem QSAT$_2$.

We introduce mixed integer bilevel linear programs (MIBLP) to compute core prices, and effective column and constraint generation algorithms to solve the problems. While full core stability becomes quickly intractable, we show that small but realistic problem sizes can actually be solved if the designer limits attention to deviations of small coalitions. This n-coalition stability is a practical approach to tame the computational complexity of the general problem and at the same time provide a reasonable level of stability.

2 - Non-monetary coordination mechanisms for time slot allocation in warehouse delivery

Paul Karaenke, Martin Bichler, Sören Merting, Stefan Minner

Recent empirical evidence suggests that retail logistics suffers from a lack of coordination. While carriers try to optimize their routes, they often experience very long waiting times at loading docks, which renders their individual planning useless. To reduce such inefficiencies, carriers need to coordinate. This problem has received considerable attention in practice, but the design of coordination mechanisms is challenging for several reasons: First, the underlying package assignment problem is an NP-hard optimization problem. Second, efficiency, incentive-compatibility, and fairness are important design desiderata for coordination mechanisms, but in most economic environments they are conflicting. Third, logistics is competitive and price-based mechanisms where carriers might have to pay for time slots suffer from low adoption. We draw on recent advances in market design, more specifically randomized matching mechanisms, which set incentives for carriers to share information truthfully such that a central entity can coordinate their plans in a fair and approximately efficient way. This yields a new and powerful approach for coordination in logistics. We report numerical experiments based on field data from a real-world logistics network to analyze the average reduction in waiting times and the computation times required. Our results show that randomized matching mechanisms provide an effective means to reduce waiting times at warehouses without requiring monetary transfers by the carriers. They are computationally efficient and provide a practical solution to wide-spread coordination problems.

3 - Taming the Communication and Computation Complexity of Combinatorial Auctions: An Experimental Study of the FUEL Bid Language

Gregor Schwarz, Martin Bichler

Combinatorial auctions have found widespread application when allocating multiple items in the presence of complex bidder preferences. The enumerative XOR bid language is a prominent format for such auctions despite its susceptibility to the missing bids problem and its

computational intractability for many applications. The FUEL bid language addresses these issues by giving bidders the possibility to express their preferences in an intuitive and compact manner. It was proposed by the C-Band-Alliance, a consortium of satellite companies, which plans to use the FUEL bid language in a private auction to sell 200 MHz of C-band satellite spectrum for terrestrial wireless use. The winner determination problem of the FUEL bid language is, however, NP-complete as we will show, and due to the vast amount of binary variables and constraints present in the allocation problem, it is far from obvious that it can be solved in a reasonable amount of time. To investigate this question, we introduce a mathematical model of the allocation problem and conduct an extensive set of computational experiments. Our tests show that solving the winner determination problem of the FUEL bid language is computational tractable for real-world applications like the C-band auction.

■ TE-15

Thursday, 15:45-17:00 - ZEU/160/H

Results and Algorithms for Layout Problems

Stream: Discrete and Integer Optimization
Invited session
Chair: *Anja Fischer*

1 - Layout problems with reachability constraint

Michael Stiglmayr

The optimal layout of a parking lot, warehouse or seating often comes with the constraint that each of the individual spaces (parking spaces, storages, seats) has to be accessible directly from a corridor/street. Two different approaches to model this reachability constraint will be presented: an integer programming approach modeling the distance to the exit and a network flow formulation. Neglecting some of the real-world requirements the admissible region is discretized into unit squares representing either an individual space or being part of a corridor/street. The objective is then to maximize the number of individual spaces (or equivalently to minimize the number of street fields). One can show that in an optimal solution the corridors/streets build a tree whose leafs represent the individual spaces. We present a heuristic approach to efficiently generate a very good feasible solution, and a bounding scheme for the maximal number of individual spaces.

2 - An extended polyhedral study of the betweenness model

Frank Fischer, *Anja Fischer*

The so called betweenness model is widely used in the literature ranging from the minimum linear arrangement problem, to the single-row facility layout problem (SRFLP) to fixed-row multi-row problems. In this talk we present new classes of valid inequalities for the betweenness model. These inequalities generalize constraints introduced by Amaral for the SRFLP. We show how to separate the newly derived inequality heuristically. These separators are combined in a cutting plane approach. Finally we present some preliminary computational results. These show that our new approach allows to solve more instances to optimality than the lower bounding approach of Amaral for the SRFLP.

3 - Solving extended row layout problems

Anja Fischer, *Mirko Dahlbeck*, *Frank Fischer*

In this talk we consider layout problems from real-world factory planning. Given a set of departments and pairwise connectivities between these departments, the classic single-row facility layout problem (SRFLP) asks for a non-overlapping arrangement of these departments in a single row such that the weighted sum of the center-to-center distances is minimized. In this talk we extend the well-known betweenness model for the SRFLP by Amaral such that arbitrary positions of the input and output points of the departments, asymmetric connectivities representing the amount of transport between the departments as well as asymmetric clearances between the departments can be handled. Clearance conditions enlarge the minimal allowed distance between (neighboring) departments, e.g., due to safety-restrictions or to access the control panels. Furthermore, we allow a shared use of additional clearances between neighboring departments. In addition to the order of the departments the exact positions of the clearances have to be determined. We show that given the order of the departments optimal positions of the additional clearances can be determined in polynomial time. Furthermore we extend our model to the parallel row ordering problem and to multi-row facility layout problems with fixed row assignment in general. In contrast to the literature we allow the consideration of clearance conditions between departments in different rows. Finally we present some preliminary computational results.

Thursday, 17:15-18:45

Friday, 9:00-10:40

■ FA-01

Friday, 9:00-10:40 - POT/006/H

Scheduling Theory and Applications

Stream: Project Management and Scheduling
Invited session
Chair: *Klaus Jansen*

1 - A problem specific genetic algorithm for disassembly planning and scheduling considering process plan flexibility and parallel operations
Franz Ehm

Increased awareness of resource scarcity and man-made pollution has driven a rethinking of our way to deal with end-of-life products. There are legal directives but also economic incentives for consumers and manufacturers to exploit the remaining value by means of repair, remanufacturing or at least recycling. Typically, disassembly is needed as a prerequisite to access usable structures. To compensate for a relatively low value added, efficent utilization of technical equipment and workers should be emphasized by carefully planning and scheduling the required disassembly tasks. The variety of feasible process plans as well as the large number of emerging parts and sub-assemblies in disassembly generally make for a challenging optimization problem. Its complexity is further accentuated by considering divergent process flows which result from multiple parts or sub-assemblies that are released in the course of disassembly. In a previous mathematical modelling approach And/Or graphs were used to represent the product structure and derive disassembly specific process plans. However, computational tests with varied problem specifications showed that exact solution using the existing mixed integer linear programming (MILP) formulation is only practical for smaller problem instances. Consequently, a meta-heuristic approach is taken to enable solution of large size problems. This study presents a genetic algorithm (GA) along with a problem specific representation to address both the scheduling and process planning aspect while allowing for parallel execution of certain disassembly tasks. Artificial test data is used to analyze problem specific operators and adjust appropriate parameter settings. Subsequently, the computational performance of the GA is evaluated in comparison to the MILP formulation and its application to industrial sized problems is discussed.

2 - Scheduling on a single machine with fixed departure dates and multiple customers to minimize holding and transportation costs
David Bachtenkirch, Stefan Bock

The coordination of production and delivery schedules is a highly relevant topic in modern supply chains. In many cases manufacturers rely on third-party logistics providers who transport produced goods, where delivery pickups at the production site occur at predefined dates. In this setting, jobs which complete production before their assigned departure date must be held in inventory. We assume that delivery costs can be reduced by bundling jobs as delivery batches.

We consider a dynamic integrated scheduling problem with hard time windows. Jobs must be produced on a single machine and be delivered to different customers up until a delivery deadline. At fixed dates, already completed jobs are eligible for batch delivery. The objective is to minimize total holding and transportation costs. This optimization problem is solved by a best-first branch and bound approach. The problems structure allows the application of several dominance criteria which reduce the number of nodes that need to be investigated in the search process significantly. In our computational study, we test our branch and bound approach against a commercial MILP solver on generated instance sets with different characteristics. The results show that our approach outperforms the commercial solver on all tested instances.

3 - Proactive and reactive approaches for soccer scheduling
Dries Goossens, Xiajie Yi

Each soccer competition needs a schedule of play indicating which team is facing which opponent at what time (and where). Most leagues use a round robin schedule, where each team plays against each other team an equal number of times. Despite hard efforts invested at the beginning of the season to create a high-quality soccer schedule, this initial schedule is not necessarily fully played as planned. Indeed, several months can span between the time the initial schedule is announced and the moment that some games are played. During this period, additional information becomes available, e.g. related to weather conditions, the outcome of other competitions (e.g. domestic cup, Champions League, etc.), technical problems (e.g. defective stadium lights), etc. This information is difficult to estimate and anticipate due to uncertainty. Nevertheless, it may lead to the pause, postponement, or even cancellation of a match. The games that are postponed or rescheduled induce deviations from the initial schedule, which we call disruptions.

We study the difference between the quality of the initial schedule and that of the effectively realized schedule for fifteen seasons of ten major European soccer leagues. We introduce quality measures that are based on breaks, fair ranking, and failures. For a given schedule, we say that a team has a break if it has two consecutive home games, or two consecutive away games. Fair ranking refers to the fact that the number of (home) games played should be balanced over the teams at any point in the season. Failures represent matches that cannot be (re)scheduled. Our motivation to consider these quality measures stems from a survey of European soccer schedules, which shows that in almost all competitions, schedules are used that minimize the number of breaks and balance the home advantage. We find that, although unforeseen events rarely interfere with a match, for almost 90% of the seasons, the initial schedule is different from the realized schedule. Furthermore, these disruptions have a profound impact on the quality of the realized schedules.

To mitigate the impact of unforeseen events on the quality of the schedule, we develop proactive and reactive scheduling approaches. Proactive scheduling focuses on developing an initial schedule that anticipates the realization of unpredicted events during the season. We do this by inserting so-called catch-up rounds (i.e. empty rounds, to which matches can be rescheduled when unexpected events occur) as buffers in the schedule. Reactive scheduling, on the other hand, repairs the initial schedule when a disruption occurs. Hence, our reactive policies concentrate on rescheduling postponed games to appropriate catch-up rounds. We compare various combined proactive and reactive strategies, and study their effect on the quality of the schedule.

4 - On Integer Programming and Convolution
Klaus Jansen

Integer programs (IP) with a constant number m of constraints are solvable in pseudo-polynomial time. We give a new algorithm based on the Steinitz Lemma and dynamic programming with a better pseudo-polynomial running time than previous results. Vectors v_1,...v_n in Rm that sum up to 0 can be seen as a circle in Rm that walks from 0 to v_1 to v_1 + v_2, etc. until it reaches v_1 + ... + v_n = 0 again. The Steinitz Lemma says that if each of the vectors is small with respect to some norm, we can reorder the vectors in a way that each point in the circle is not far away from 0 w.r.t. the same norm. We show in the talk that a solution to the IP max cT x, A x = b, x >= 0, x in Zn can be found in time O(m Delta)2m log(||b||_infty) + O(nm) where Delta is the biggest absolute value of any entry in A.

Moreover, we establish a strong connection to the problem (min, +)-convolution. (min, +)-convolution has a trivial quadratic time algorithm and it has been conjectured that this cannot be improved significantly. We show that further improvements to our pseudo-polynomial algorithm for any fixed number m of constraints are equivalent to improvements for (min, +)-convolution. This is a strong evidence that our algorithm's running time is best possible. We also present a faster specialized algorithm for testing feasibility of an integer program with few constraints. Our algorithm for the feasibility problem runs in O(m Delta)m log(Delta) log(Delta + ||b||_infty) + O(nm). Finally we show for the feasibility problem also a tight lower bound, which is based on the Strong Exponential Time Hypothesis (SETH), and give some applications for knapsack and scheduling problems.This is joint work with Lars Rohwedder (Univ. Kiel).

■ FA-02

Friday, 9:00-10:40 - POT/051/H

Shared Logistics Services

Stream: Logistics and Freight Transportation
Invited session
Chair: *Pirmin Fontaine*

1 - Emission limits and emission allocation schemes in intermodal rail/road freight transportation

Arne Heinold, Frank Meisel

In this talk, we consider a freight routing problem for a set of environmentally aware customers that request to ship orders with no more than a specified amount of greenhouse gases, so-called emission limits. In order to comply with each orders' emission limit, not just a route plan but also an emission allocation rule needs to be identified. For this purpose, we combine a service network design problem for the routing of freight shipments in an intermodal rail/road network with two schemes (egalitarian and payload-based) for allocating emissions among those shipments that share a service. We add emission limits as constraints to the problem. Penalty costs occur if the limits cannot be met for all orders simultaneously. We implement this extended service network design problem formulation with the IBM ILOG CPLEX Optimization Studio software. The obtained optimal solutions contain an individual routing plan for each order as well as an optimal emission allocation scheme for each service. We apply our model to a realistic intermodal rail/road network in Europe and compare solutions that minimize total emissions with solutions that minimize total transportation cost. Our experiments indicate that allocation schemes for services can have a strong impact on the obtained solutions. Thus, applying an identical allocation scheme to all services is not optimal and increases both, total emissions and total costs. Our experiments further indicate that there is a strong impact of emission limits on the overall objective value. Often, an optimal solution accepts penalty costs for not fulfilling emission limits although a solution without penalty costs exists.

2 - Solving the bi-objective multimodal car-sharing problem including time-dependent user preferences

Sophie Parragh, Miriam Enzi, Jakob Puchinger

The success of shared mobility systems largely depends on the users' satisfaction with the system. In the bi-objective multimodal car-sharing problem we aim at determining the optimal mode of transport (MOT) (car, bike, public transport and walking) for each sequence of user tasks, starting and ending at one of the depots, and to schedule the tours of available cars by concurrently minimizing cost and maximizing user satisfaction. The number of available cars is limited and they may be used by different users throughout the day. We consider time-dependent user preferences for the different considered MOTs: 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. The underlying optimization problem is modeled in terms of a mixed integer linear program. Small instances can be solved to optimality by embedding the proposed model into the well-known epsilon-constraint scheme. For instances of realistic size, we employ advanced exact and heuristic search techniques. We compare several different variants of the problem (fixed and variable task sequences as well as fixed and time-dependent MOT-preferences) on a set of realistic instances; and we analyze the trade-off relationship between cost and user satisfaction.

3 - Sharing the Last Mile: Business Models and Dispatching Schemes for Flexible and Green Last Mile Deliveries

Pirmin Fontaine, Stefan Minner, Maximilian Schiffer

Urbanization and its negative externalities are soaring all around the world. Simultaneously, rapidly growing e-commerce causes significantly increased and more fragmented deliveries in cities. All stakeholders involved suffer from these developments and struggle with individual problems: municipalities struggle to design regulations that lead to sustainable infrastructure and systems. Logistics service providers (LSPs) struggle between fulfilling customer requirements and economically meeting emission regulations. Citizens perceive a reduced quality of life, e.g., due to, congestion and unreliable services. Striving to resolve personal harm, multiple stakeholders aim to reduce these negative externalities, fostering solutions that may negatively impact each other due to conflicting objectives, e.g., the user equilibrium of last mile distribution realized by LSPs will deviate from the system optimum desired by citizens and municipalities. Green transportation modes, e.g., electric scooters or cargo-bikes, offer possibilities to reduce emissions but require high-demand areas to be economically efficient. Such areas are harder to realize if demands are split on different transport modes since pooling effects might be lost.

We provide an optimization framework that allows to assess the benefit of different transport modes as well as the impact of sharing between a multitude of LSPs. Designing a bilevel program, we consider the interaction between different LSPs through pricing and sharing mechanisms. At the upper level, different mechanisms and incentives such as legislative enforcements, monetary incentives, subsidized micro-depots, and a centrally organized solution as an outsourcing option are modelled as leader decisions. On the lower level, we develop a new continuous approximation scheme, capturing the operational complexity of the addressed planning problem by considering multimodal fleets in shared delivery areas. With this framework, we analyze the impact of i) cost and information sharing, ii) different delivery modes depending on zone and demand assignment, iii) municipal regulations and pricing mechanisms, iv) service region design, v) and the environmental impact.

We present a real-world case study for an urban area with a multitude of LSPs, each of them operating its own fleet with a single transportation mode in a status quo scenario. We calculate an upper bound on the improvement potential, assuming a centrally coordinated multi-modal system. In between, we account for different business models using different degrees of sharing and operation: we calculate i) results for each LSP operating its own single or multimodal fleet, and ii) the effects of outsourcing to a centrally operated system. We show how demand profiles and regulations foster specific business models and the different objectives.

4 - Strategic Network Design for Last-mile Delivery with Crowd Resources

Santiago Nieto-Isaza, Pirmin Fontaine, Stefan Minner

Last-mile delivery is one of the key problems in Urban Logistics which has received much attention from practitioners, academia and the media. The relevance of this problem, enhanced by the growth of urban population and the increasing trend towards e-commerce has brought many innovative initiatives. Crowdsourced delivery, which is the concept of relying part of the delivery orders on a pool of people instead of professional couriers, is one of the possible solutions to mitigate the negative effects of the growing demand for parcel delivery services in urban areas. We investigate a last-mile transportation network where the parcels are delivered by members of the crowd - e.g. regular commuters using public transport. The capacity of the network depends on the stochastic availability and willingness of the crowd members to transport parcels. Therefore, professional couriers operate as a back-up option to guarantee the deliveries. Besides direct shipments, transportation via mini-depots that have to be placed into the network allows more flexibility. We present a two-stage Stochastic Network Design Problem for Multi-commodity Flows where the capacity of the arcs in the network is considered to be stochastic. The first stage of the problem is the decision of locating the mini-depots used for decoupling flows. The second stage of the problem is the decision of the allocation of the demand (delivery orders) to the transportation network using the available modes, i.e. crowd members or professional couriers for a finite set of scenarios. We use a space-time representation of the transportation network to model the time-dependency of the multi-commodity flow problem. To model the stochastic capacity of the arcs in the network, we use a space-time Poisson-Gamma process. We propose an exact algorithm using Benders Decomposition embedded in a Branch-and-Cut framework. To enhance the algorithm, we use Partial Benders Decomposition and Pareto-Optimal cuts.

Computational experiments are conducted for network settings inspired by the public railway transportation corridor of the city of Munich on randomly generated scenarios. To show the benefits of a crowd-based strategy, we compare each instance to problem settings with no availability of the crowd and/or no mini-depots for parcel transshipments, i.e. only perfect origin-destination matchings are allowed. The experiments show that the proposed network scheme using crowd members and mini-depots for parcel transshipments allow cost reductions between10% and 30% of the total expected cost, compared to different schemes with no relay points or no crowd availability. The proposed algorithm outperforms a commercial solver in both execution times and optimality gaps

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■ FA-03

Friday, 9:00-10:40 - POT/081/H

GOR Young Researchers Award

Stream: GOR Award Winner Presentations

Invited session

Chair: *Alexander Martin*

1 - Computation of weighted sums of rewards for concurrent MDPs

Dimitri Scheftelowitsch

We consider sets of Markov decision processes (MDPs) with shared state and action spaces and assume that the individual MDPs in such a set represent different scenarios for a system's operation. In this setting, we solve the problem of finding a single policy that performs well under each of these scenarios by considering the weighted sum of value vectors for each of the scenarios. Several solution approaches as well as the general complexity of the problem are discussed and algorithms that are based on these solution approaches are presented. Finally, we compare the derived algorithms on a set of benchmark problems. Our results suggest that problem-specific heuristic approaches are not only much faster in terms of time complexity when compared to exact solvers, but also produce policies which are very similar in performance to the optimal ones.

2 - The nucleolus and inheritance of properties in communication situations
Bas Dietzenbacher

This paper studies the nucleolus of graph-restricted games as an alternative for the Shapley value to evaluate communication situations. We focus on the inheritance of properties of cooperative games related to the nucleolus: balancedness (the nucleolus is in the core), compromise stability and strong compromise admissibility (these properties allow for a direct, closed formula for the nucleolus). We characterize the families of graphs for which the graph-restricted games inherit these properties from the underlying games. Moreover, for each of these properties, we characterize the family of graphs for which the nucleolus is invariant.

■ FA-04

Friday, 9:00-10:40 - POT/106/U

Control Theory and Continuous Optimization I

Stream: Control Theory and Continuous Optimization
Invited session
Chair: *Oliver Stein*

1 - Nonlinear Optimization of District Heating Networks
Richard Krug, Martin Schmidt, Volker Mehrmann

We develop a complementary constraint nonlinear optimization model for the time-dependent control of district heating networks. The main physical aspects of water and heat flow are governed by nonlinear partial differential equations in these networks. In addition, a pooling-type mixing model is required at the nodes of the network for treating mixing of different water temperatures. This mixing model can be recast using suitable complementarity constraints. Thus, in total we face an MPCC with nonlinear PDEs. We then apply suitable discretizations in space and time to obtain finite-dimensional optimization problems with complementary constraints. For the MPCC aspects we develop suitable NLP reformulations and finally present numerical results for the finite-dimensional problems as well as for an instantaneous control approach.

2 - Optimal control of transportation networks
Simone Göttlich

Differential equations on networks have nowadays a broad spectrum of applications. They are widely used to describe transport phenomena such as traffic flow, gas or electricity. We explain the mathematical challenges behind the network approach and give an idea how control strategies can influence the nonlinear dynamics. Numerical results are presented to demonstrate different solution techniques.

3 - Inner parallel cuts for mixed-integer convex optimization problems
Christoph Neumann, Oliver Stein

We introduce an inner parallel cutting plane method (IPCP) to compute good feasible points for mixed-integer convex optimization problems. The method iteratively generates polyhedral outer approximations of an enlarged inner parallel set (EIPS) of the continuously relaxed feasible set. This EIPS possesses the crucial property that any rounding of any of its elements is feasible for the original problem. The outer approximations are refined in each iteration by using modified Kelley cutting planes, which are defined via rounded optimal points of linear optimization problems (LPs).

We show that the method either computes a feasible point or certifies that the EIPS is empty. The crucial advantage of the method lies in the complexity of each iteration: While other approaches need to solve a mixed-integer linear optimization problem, the IPCP only needs to solve an LP, which can be carried out efficiently. Our computational study indicates that the IPCP is able to quickly find feasible points for many practical applications. It further demonstrates that the objective values of the computed feasible points are generally of good quality and sometimes not easily obtainable by other methods.

4 - 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.

■ FA-05

Friday, 9:00-10:40 - POT/112/H

Delays in railway operations

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Matthias Müller-Hannemann*

1 - Data Analytics in Railway Operations: Using Machine Learning to Predict Train Delays
Florian Hauck, Natalia Kliewer

Due to uncontrollable external influences and high capacity utilization of the infrastructure, train delays cannot be avoided completely. Especially in large railway networks, delays occur on a daily basis and are still a major problem for railway companies. To limit the negative effects of delayed trains, it is important to know about future delays as early and as precisely as possible. This gives railway operators a chance to react accordingly and provide alternative connections for passengers. Current prediction methods are mostly based on simple static rules or on expert knowledge and their results are often imprecise. Inaccurate predictions complicate the real-time planning process for railway operators and have a negative impact on the customer satisfaction. Our aim is to analyse historical delay data and to use that information to build machine-learning models that can improve prediction accuracies for train arrival and departure times.

We present a machine-learning approach to predict the event times of trains in the German railway network. Following the Cross-Industry Standard Process for Data Mining (CRISP-DM), we first show how we collected and prepared historical train delay data from the German railway company Deutsche Bahn. The dataset includes the arrival and departure times of all trains that used the German railway infrastructure in one year. First, we transformed the dataset such that event times from other trains can be used as input features for the target train. After transforming and cleaning the dataset, a linear regression model and a neural network model are trained to predict future train events. The two models use event times from other trains in the network and weather information as input features. In a preprocessing step, a set of trains that could potentially influence the event times of the target train is selected. Next, a smaller subset of actually relevant input features is selected through a greedy forward feature selection method. The standard protocol of cross-validation is applied to avoid overfitting. Two static prediction methods are introduced and used as a benchmark to evaluate the accuracies of the proposed machine-learning models. An exemplary train line is selected to evaluate the prediction models. The

results show that the neural network approach performs better than all the other models. Even for predictions that lie more than five hours in the future, the neural network outperforms the benchmark approaches and achieves useful accuracies.

2 - Decision Support for Passenger-Oriented Train Disposition with Vehicle Capacity Restrictions

Matthias Müller-Hannemann, Frank Berger, Ralf Rückert, Sebastian Schmidt

In large and complex public transportation systems delays as well as disruptions occur frequently. As a consequence, passengers may miss some planned transfer which results in significant delay at their destinations, in considerable dissatisfaction, and ultimately in economic loss for the railway company. In delay management, train dispatchers have to decide which trains shall wait for delayed incoming trains in order to maintain connections for passengers.

In an on-going joint research project with Deutsche Bahn we are working on the development of a decision support system for dispatchers which shall help to find optimal waiting decisions from a passenger's point of view. A key assumption is that detailed information about passenger flows is available, that is, for each passenger the planned route is known. Such passenger flows can be based on sold tickets or statistically validated demand models. In this project we have built a prototype for an optimized passenger-friendly disposition system, named PANDA (Rueckert et al., Public Transport 9(1):307-324, 2017).

If trains are cancelled or connections cannot be maintained, passengers have to be rerouted. State-of-the-art solutions determine new routes for passengers that are optimized subject to earliest arrival at the planned destination with few transfers as a secondary criterion. Recent progress in shortest path algorithms for such applications allows to solve such problems in a few milliseconds per instance.

Vehicle capacity constraints, however, are widely neglected in previous work. Considering the available free capacity to avoid overcrowded trains leads to several, more challenging combinatorial optimization problems. With respect to capacities, we may distinguish between hard and soft capacities. For each vehicle, there is a designated number of available seats. This gives a soft capacity beyond which it becomes more and more uncomfortable to travel. At a certain threshold, the hard capacity, a vehicle becomes so crowded that it is not allowed to run anymore for security reasons.

In this work we take the perspective of a recommendation system which tries to minimize the overall inconvenience for all passengers. Inconvenience can be expressed in several ways, the simplest version being the total delay at destination. Overcrowding of trains can be penalized with the help of convex cost functions. This leads to large-scale integral minimum cost multi-commodity flow problems, where each group of passengers sharing the same origin and destination corresponds to some commodity. The most common approach to solve them is integer linear programming (ILP) with a path-based formulation and column generation. While the underlying network is fairly large, the number of commodities to be considered is typically of moderate size. Moreover, for each commodity, there is only a limited number of "reasonable" alternative paths to which one can heuristically restrict the search.

3 - Delay Management respecting the "trickle-in" effect

Anita Schöbel, Julius Pätzold, Jörg Müller

Delay management deals with the decisions if a train should wait for a delayed connection or if it should depart on time. Models for delay management exist and can be adapted to capacities of stations, capacities of tracks, or respect vehicle and driver schedules and other constraints.However, what has been neglected so far is that trains cannot depart as planned if passengers from another train trickle in one after another such that the doors of the departing train cannot close. This effect is often observed in real-world, but has not been taken into account in delay management so far.

We show the impact that this "trickle-in" effect has on the departure delays of trains under different conditions. We then modify existing delay management models to take the trickle-in effect into account. This can be done by forbidding certain intervals for departure. We present an integer programming formulation taking these constraints into account resulting in a generalization of classic delay management models. We analyze the resulting model and show how the necessary data can be approximated best. Experimentally we show the impact of this effect on the objective value and on the computation time of the delay management problem.

■ FA-06

Friday, 9:00-10:40 - POT/151/H

Energy system and operational planning

Stream: Energy and Environment
Invited session
Chair: *Matthew Schmidt*

1 - A bottom-up optimization model for electricity generation and energy policy using positive mathematical programming

Insook Kim, Dongwoo Kim

It is widely acknowledged that the power generation sector is a major source of greenhouse gas emissions. An optimization model describing technology selection, such as linear programming (LP), has been used to analyze and evaluate the effects of the greenhouse gas emission mitigation policies in the power generation sector. There are many energy models to minimize the system cost using linear programming, for example, the Energy Technology and Systems Analysis Program's MARKet ALlocation (MARKAL), The Integrated MARKAL-EFOM System (TIMES), and and International Atomic Energy Agency's Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE). However, LP has limitations in describing practical technology selection and reproducing base-year technology selection. The LP solution is an extreme point of the binding constraints. When the basis matrix has a rank less than the number of observed baseyear activities, the resulting optimal solution will suffer from overspecialization of technology selections compared to the base year. The common approach used to overcome the limitation is to add supplementary constraints to recover plausible technology selections. It usually adds constraints to place the solution within plausible bounds. The boundary constraints can make the solution of the model be the actual technology selection. Such solutions are often controlled by subjective constraints and thus locked in the context of the constraint. Additionally, whether the policy simulation results stem from policy changes or constraints is ambiguous because the constraints also affect the model's responses to policy changes. In many previous studies for power generation sector, the limitations of LP-based models are rarely mentioned. They have used upper bounds on variables to adjust the rate of new processes or made some assumptions which might cause the potential problems. Mixed integer programming can be employed to describe more realistic power generation systems, but hard to overcome the fundamental limitations of LP. Positive mathematical programming (PMP) can be considered as an alternative method to overcome the limitations of LP when constructing a bottom-up model of the power generation sector. Providing an interior solution without any subjective constraints, PMP can avoid the model's impractical technology selections and describe more flexible and clear reactions to external changes. The purpose of this study is to apply PMP to the bottom-up model of the power generation sector to overcome the limitations of the LP-based model and identifies plausibility of using PMP in a forward-looking optimization model of the power generation sector.

2 - Operational Plan for an Energy Plant Considering the Fluctuation of the Spot Price of Electricity

Masato Dei, Tomoki Fukuba, Takayuki Shiina, Ken-ichi Tokoro, Tetsuya Sato

Recently, environmental problems such as global warming have become serious, and as a result, efforts are being made to realize sustainable local communities with low environmental impact. One of these efforts is the development of the smart community. Tokoro and Fukuyama [1] presented the basic model of a smart community, which considers seven developmental areas: electricity, gas, water treatment, industrial, business, home, and rail. The basic model facilitates the quantitative evaluation of smart communities, which considers the interaction among the seven areas of development. In their industrial model, Suzuki and Okamoto [2] proposed benchmark energy plant planning problems for application in factories and large shopping centers. The benchmark problem is a model of an energy plant that purchases electricity and gas, and uses the equipment to meet the demand for electricity, steam, and heat. The equipment used in the benchmark problem is a gas turbine, boiler, two types of refrigerators, and heat storage tank. The objective of the benchmark problem is to develop an operational plan that minimizes the total cost of purchasing power and gas under the constraints of equipment and energy flow. In electric power planning, on any given day, it is possible to optimally manage the electricity needs for the next day, based on the spot price. The spot price is the price of power in the market on the prior day. Furthermore,

on the next day, it is possible to buy or sell the power in the market depending on whether there is a shortage or excess of power. In the case of a shortage, the price may soar, and a large loss may occur. Thus, it is necessary to make decisions under uncertain circumstances. To solve price fluctuation problems, the expected value minimization model is often considered. However, this model takes a risk-neutral position and does not consider cost fluctuations. Therefore, we use the indicator conditional value at risk (CVaR) [3], proposed by Rockafellar and Uryasev, to reduce the cost and its variability in the worst-case scenario. In this study, we extend benchmark models for factories and large shopping centers to the models which consider uncertainty, by using stochastic programming. Next, we propose a CVaR minimization model that avoids the risk of fluctuating power spot prices, and compare it with the expected value minimization model.

[1] K. Tokoro, Y. Hukuyama, Development and extension of smart community model for energy efficiency, Operations Research, Vol. 62, No. 1, pp. 44-49, (2017). [2] R. Suzuki, T. Okamoto, An Introduction of the Energy Plant Operational Planning Problem: A formulation and solutions, IEEJ International Workshop on Sensing, Actuation, and Motion Control, (2015). [3] R.T. Rockafellar, S. Uryasev, Optimization of conditional value-at-risk, Journal of Risk, Vol. 2, pp. 21-41, (2000).

3 - A Lagrangian decomposition approach to solve large scale multi-sector energy system optimization problems

Angela Pape, *Andreas Bley*, *Frank Fischer*

We consider the problem of optimizing the strategic development of a European energy supply system with a high share of renewable energy. Our model considers the energy sectors electricity, heat, and transportation, and it includes numerous types of consumers as well as power generation, storage, transformation and transportation technologies, most of which may flexibly participate in several energy sectors, together with their technical, economical, and political parameters. Given time series for the regional demands and the potential renewable production, the goal is to simultaneously optimize the strategic dimensioning and the hourly operation of all components in the system such that the overall costs are minimized. In this paper, we propose a Lagrangian solution approach that decomposes the model into many independent unit-commitment-type problems by relaxing several coupling constrains. This allows us to compute high quality lower bounds quickly and, in combination with some problem tailored heuristics, globally valid solutions with much less computational effort.

■ FA-07

Friday, 9:00-10:40 - POT/251/H

Railway rolling stock optimization

Stream: Traffic, Mobility and Passenger Transportation
Invited session
Chair: *Philine Schiewe*

1 - Optimization of Rolling Stock Rostering using Mutual Direct Operation

Sota Nakano, *Jun Imaizumi*, *Takayuki Shiina*

In railway companies, creating rolling stock schedules is a very important task because rolling stock is a limited resource and its efficient use is essential. In Japan, rolling stock schedule is defined by two stages. One is called "path" and the other is "roster". A path corresponds to the daily schedule for a certain vehicle, defined by its origin, destination, and the trains assigned to the vehicle. These assigned trains constitute a sequence that should be performed by the vehicle. Some paths include "daily inspection" which has to be performed within a predetermined daily interval, depending on the type of rolling stock at specific facilities, such as depots. A roster is a sequence of paths in which the origin of a path coincides with the destination of the proceeding path, and the sequence satisfies the condition regarding daily inspection. Each vehicle starts its duty from a certain path in the roster, respectively, and rotates one path a day along the roster. Thus, each vehicle is equivalently used in the same sequence, and the performance of inspection is guaranteed by following the roster. In large cities such as Tokyo and Osaka, different lines of different companies are directly connected, and "mutual direct operation" is employed for convenience of passengers. In mutual direct operation, trains originating from stations of a specific company terminate at stations of other companies. Mutual direct operation is an approach where each company uses other companies' vehicles in its line, by paying a fee to the owner of the vehicle depending on the total distance traveled in its line. In such cases, rosters of these companies are prepared to minimize the difference between total distances traveled, in order to simplify adjustment of paying fees to each other, as well as for the total deadhead distance. Giacco et al. proposed a mathematical model such as an integer-programming problem for obtaining an optimal roster, to make a single roster. In their model, each train corresponds to a node and possible connections between two trains correspond to arcs. A tour visiting every node just once, satisfying constraints about daily inspection, and minimizing total cost is obtained by mathematical formulation. Although this problem is similar to the Traveling Salesman Problem, it is more challenging because of inspection constraints. Morito et al. extended the model for a problem where two rosters for two types of rolling stock are simultaneously made. We extend Morito's formulation for problems in which mutual direct operation is performed. Additional constraints to the original formulation include limitations of the difference between traveling distances. Results from numerical experiments have been displayed.

2 - Robust and cost-efficient integrated vehicle and crew scheduling with controlled trip shifting

Bastian Amberg, *Boris Amberg*

In the context of vehicle and crew scheduling in public bus transport, two concepts have been intensively studied to reduce resource usage and to minimize operational costs: First, integrated, i.e. simultaneous, scheduling of vehicles and drivers. Second, resource scheduling with simultaneous trip shifting, i.e. slightly modifying the underlying timetable without changing trip durations. Applying these two concepts can lead to highly efficient and tight schedules. Unfortunately, such schedules are more susceptible to delays during operations. Even small delays may propagate and grow up to cascades of additional delays. Besides, shifting of particular trips may have an unwanted impact on the original timetable structure as e.g. headways between consecutive trips of a line may be changed.

In this work we propose a column generation based solution approach for integrated vehicle and crew scheduling with controlled trip shifting. In addition to minimizing vehicle and crew costs two further aspects are considered: First, the approach also aims at building robust schedules by minimizing the expected overall propagation of delays throughout the transportation network. To reduce the possible propagation of delays, the mutual dependencies between vehicle and driver schedules are taken into account during integrated scheduling. Second, the approach aims at minimizing changes to the original timetable structure when shifting trips. During scheduling the possibility to shift trips within small defined time windows is used for both increasing cost-efficiency and robustness. Robust and cost-efficient vehicle itineraries and driver duties are generated in the column generation pricing problems. The pricing problems are modelled as resource constrained shortest paths problems and solved by dynamic programming using a labelling algorithm. The solution approach is evaluated on real-world datasets. We examine the impacts of shifting trips on costs, robustness, and alteration of the original timetable structure.

3 - Integrated Rolling Stock and Shunting Driver Rescheduling

Rowan Hoogervorst, *Ralf Borndörfer*, *Twan Dollevoet*, *Dennis Huisman*

In rolling stock rescheduling, we assign compositions of train units to the trips in the timetable and determine the shunting actions that are needed to change the compositions between trips. These shunting actions create tasks for the shunting drivers, who are train drivers that are responsible for moving train units at the stations and at the shunting yards of a station. Hence, any changes that are made to the shunting plans in the rolling stock rescheduling phase, compared to the planned rolling stock schedule, require the duties of the shunting drivers to be rescheduled as well. Traditionally, the rolling stock rescheduling problem and the problem of rescheduling the duties of the shunting drivers are solved sequentially. This may lead to infeasibilities if the new shunting tasks cannot be executed by the number of shunting drivers that are available at a station. To overcome such infeasibilities, we propose to reschedule the rolling stock and the shunting drivers in an integrated way. In this talk, we propose an exact solution method for this integrated problem and show how this method performs on instances of Netherlands Railways (NS).

4 - Vehicle Scheduling Based on a Line Plan: Guaranteeing Feasible Periodic Timetables

Philine Schiewe, Paul Bouman, Alexander Schiewe, Anita Schöbel

In public transport planning, problems are traditionally solved sequentially. For example, a line plan is created first and used as input for finding a timetable. A vehicle schedule is then created for both the existing line plan and the corresponding timetable. However, solving these problems sequentially may lead to suboptimal solutions and even infeasibilities as the objectives of the single stages might contradict each other and specific constraints of later stages may not be included in earlier ones. While solving several, or even all, considered problems integratedly would lead to the best solutions from a quality perspective, this approach is unfortunately not feasible for many practical applications due to the inherent complexity of the integrated problems. So instead of integrating several stages, we focus on changing the sequential planning process in order to better incorporate aspects of the integrated problems. One possibility is to change the order in which the sequential subproblems are solved, for example by constructing a vehicle schedule directly for an existing line plan and fixing a timetable only later on. This poses several interesting problems. First of all, the models for the single stages have to be adapted to fit the new solution process. As a vehicle schedule traditionally relies on the departure and arrival times of trips that are fixed in the timetabling stage, we have to find models for vehicle scheduling that refrain from using these times. On the other hand, timetabling models usually do not include constraints to respect a given vehicle schedule which have to be added as well. Additionally, we have to keep the solution quality of the overall problem in mind, and especially the feasibility of the remaining stages. This means for the problem of finding a vehicle schedule based on a line plan that we have to make sure that a feasible periodic timetable still exists. Ideally, a reasonable service quality for the passengers would be guaranteed as well. For the example of finding a vehicle schedule based only on a line plan we present models and investigate the requirements for finding a feasible (periodic) timetable for the specified line plan and vehicle schedule. We test our models experimentally and compare them to the traditional sequential approach from a passengers' and an operators' point of view.

■ FA-08

Friday, 9:00-10:40 - POT/351/H

Vehicle Routing & Inventory Routing

Stream: Logistics and Freight Transportation
Invited session
Chair: *Sigrid Knust*

1 - An Integrated Clustering and Routing Algorithm for an Inventory Routing Problem

Ali Ekici, Okan Ozener

Inventory Routing Problem (IRP) arises from vendor-managed inventory business settings where the supplier is responsible for replenishing the inventories of its customers over a planning horizon. In IRP, the supplier makes the routing and inventory decisions together to improve the overall performance of the system. More specifically, the supplier decides (i) when to replenish each customer, (ii) how much to deliver to each customer, and (iii) how to route delivery vehicles between the depot and the customers. In this talk, we present a heuristic framework that integrates clustering and routing phases for an inventory routing problem where the supplier's goal is to minimize total transportation cost over a planning horizon while avoiding stock-outs at the customer locations. In the clustering phase, we partition the customer set into clusters such that a single vehicle serves each cluster. In the routing phase, we develop the delivery schedule for each cluster. The novelty of the proposed approach is that it takes the three main decisions (when to deliver, how much to deliver and how to route) into account when partitioning the customer set and forming the delivery schedule for each cluster. We compare the proposed solution approach against the ones in the literature and obtain significantly better results in terms of both the number of instances that have been solved and the quality of the solution found.

2 - Consistent Delivery Schedules in Stochastic Inventory Routing

Sebastian Malicki, Emilio Jose Alarcon Ortega, Stefan Minner, Karl Doerner

The Inventory Routing Problem resembles the Vendor Managed Inventory approach, which is widely used in practice. When applying it, lot-sizing and vehicle routing problems are solved in an integrated fashion rather than solving them sequentially as with Retailer Managed Inventories. High savings are obtained by synchronizing the delivery schedules of proximate customers or those who can be combined in favorable routes regarding time windows or other conditions. The majority of research in this field aims at finding delivery schedules that minimize routing and/or holding costs over a given planning horizon. This may however result in unfavorable delivery schedules regarding consistency for both vendors and retailers. In practice, fully flexible delivery schedules will introduce planning nervousness, whereas consistent schedules may reduce planning difficulties. Although imposing consistency increases total costs in terms of routing and holding costs, consistent schedules are preferred by both vendors and retailers as they facilitate their collaboration through reduced operational complexity. Moreover, they lead to an improved service through reduced planning nervousness. Hence, in this paper, we propose a formulation of the stochastic Inventory Routing Problem with consistent delivery schedules. First, we formulate the stochastic dynamic program and model it as a Markov decision process. Due to the problem's complexity and the curse of dimensionality, we make use of Approximate Dynamic Programming to solve larger instances. We quantify the cost of consistency under different levels of demand variation on long-haul and short distance instances. We investigate the effect of various problem parameters such as target service levels, holding costs and vehicle capacities on the resulting delivery schedules. Our results show that consistent delivery schedules with Vendor Managed Inventories are still advantageous compared to Retailer Managed Inventories and thus highly attractive for practitioners. Further, we show how customer proximity influences delivery schedules and customer service under different vehicle capacities.

3 - A Solution Approach to the Vehicle Routing Problem with Perishable Goods

Boris Grimm, Ralf Borndörfer, Mats Olthoff

Companies that sell goods to customers at multiple locations have to come up with a dedicated plan how to distribute their products over the different locations to perfectly fit the customer demand. With the increasing amount of accessible (personalized) customer data predictions of the individual demand at each location can be done more precisely. As a consequence the deliveries to take care of the stock of each product can also be planned more precisely according to the actual demand and stock to reduce stock cost and possible revenue losses for articles that might be out of stock. To plan these deliveries optimization problems from the field of vehicle routing problem arise naturally. These problems get more complex the more additional constraints modeling characteristics of goods, vehicles, or strategic respectively tactical decisions are integrated. Lahyani et. al. (2015) call these problems rich vehicle rotation problems. One special case of these problems is the case this paper focuses on where perishable goods were considered. For that reason each product has a due date to which deliveries have to be performed. Too late deliveries have a direct impact on the revenues for these products. Hence, a precise demand prediction is even more important since it is impossible to store the products for a long time. Moreover it could be the case that the due dates are dependent of other influences like weather conditions, temperatures or vehicle types used to transport them. The problem we are dealing with was defined for the AIMMS MOPTA Optimization Modeling Competition 2018. It came with a detailed problem description and a set of historical weather features which had an influence on the demand and the driving times of the vehicles used to operate the deliveries. With these data a precise prediction on the demands and weather conditions on a fixed date and an optimized plan to deliver perishable products to a set of customers should be made. In this paper we present the definition and a solution approach to the Vehicle Routing Problem with Perishable Goods including the procedure how the historical weather data was used to predict the driving times and the demands. We test the approach, which let our team finish second place in the MOPTA Competition 2018, on different data sets given by the competition. Finally, we discuss the quality of the approach in terms of runtime and quality of the computed solutions.

4 - The exponential multi-insertion neighborhood for the vehicle routing problem with unit demands

Benjamin Graf, Jan-Niklas Buckow, Sigrid Knust

Angel et al. (2008) describe an exponential neighborhood for the Vehicle Routing Problem with Unit Demands (VRPU). A neighboring solution is obtained by removal of a node subset and its subsequent reinsertion, whereby at most one removed node is inserted between

two non-removed nodes. For a given subset, a minimum cost reinsertion can be computed in polynomial time. While the original paper provides the reinsertion algorithm, it does not discuss the removal of node subsets. In this work, we analyze theoretical properties of the neighborhood, propose various node removal strategies and compare the resulting algorithms with heuristic solvers from the literature.

■ FA-09

Friday, 9:00-10:40 - POT/361/H

Facility Location, Covering, and Transport in Health Care

Stream: Health Care Management
Invited session
Chair: *Martin Comis*

1 - Medical Supply in Emergency Cases

Manuel Streicher, Sven Krumke, Eva Schmidt

The medical treatment of emergencies is one of the most important issues in health care. Among others, key issues are the problem of strategically planning facilities for emergency doctors and creating shift schedules for the doctors ensuring sufficient medical care for the population. The greatest challenge here, of course, is the uncertainty in the demand for emergency doctors. Further the tight budget in the health care sector and the demographic change in the population need to be incorporated. Within the joint project HealthFaCT we model these problems using concepts of discrete robust optimization. In this talk we present results based on real field data and compare the solutions of our models to the status quo. The comparison is done by an event based simulation on the field data using a simple greedy strategy for both the status quo and the computed solutions. On the basis of these results we discuss practicability of the proposed models.

2 - Local Search via Improvement Graphs for the Planning of Out-of-Hours Services for Pharmacies

Timo Gersing, Christina Büsing, Arie Koster, Robert Lipp

The supply of pharmaceuticals is an integral part of a functioning health care system. In the German health care system, the chambers of pharmacists are legally obliged to ensure that every citizen can reach an open pharmacy at any day and night time within an appropriate distance. To that end, the chambers of pharmacists create an out-of-hours plan for a whole year in which every pharmacy is assigned some 24-hours shifts. These shifts are important for a reliable supply of pharmaceuticals in the case of an emergency but also unprofitable and stressful for the pharmacists. Therefore, we are interested in an efficient planning that meets the citizens needs and reduces the assigned workload of the shifts on the pharmacists. An important role in controlling the workload is played by granting periods of rest between two out-of-hours services of the same pharmacy. Not least due to these periods of rest, it is strongly NP-hard to decide whether there exists any feasible plan to a given instance, which raises the interest in heuristic approaches.

In this talk, we propose a local search algorithm for the planning of out-of-hours services that aims to improve the compliance with periods of rest. The local search is based on improvement graphs, which are generally used for a systematic modeling of large and complex search neighborhoods. In these neighborhoods, one efficiently searches for the best neighbor by solving an auxiliary optimization problem on the improvement graphs. In our case, the improvement graph models a chain of reassignments of out-of-hours services from one pharmacy to another in order to avoid two close services of the same pharmacy. A chain of reassignments corresponds to a path in the improvement graph and the benefit of the reassignments is reflected by the cost of the path. Hence, we reduce the problem of finding the best neighbor to computing a shortest path in the improvement graph.

We focus the discussion on how to define the set of arcs in the improvement graph and their costs such that we have the desired correspondence to the chains of reassignments. Furthermore, we show computational results on the performance of this local search algorithm.

3 - Strategic Planning for Mobile Medical Units under Unsteerable Uncertain Demands

Martin Comis, Christina Büsing, Eva Schmidt, Manuel Streicher

Mobile medical units (MMUs) represent a relatively new concept for supplying primary health care in predominantly rural environments. MMUs are small movable practices that can, in large parts, provide equivalent health services as regular primary care practices. This mobility allows for a demand-oriented, flexible, and local provision of primary care. To ensure the general acceptance of an MMU service, MMUs are commonly operated in sessions according to a weekly reoccurring schedule. The strategic planning problem for MMUs (SPMMU) provides the basis for such a schedule: Given a set of potential MMU operation sites, a set of existing primary care practices, and a set of aggregated patient demand origins; decide how many MMU sessions shall be operated at each site in the course of a week in order to meet all patient demands at minimum cost. In doing so, we distinguish two types of patient demands: First, the steerable demand corresponding to patients who announce themselves through, e.g., a centralized appointment system, and can be steered to any treatment location within a given consideration set. Second, the unsteerable demand representing walk-in patients that always visit the closest operating treatment location.

In this talk, we present a linear integer programming formulation for the SPMMU. Realizing that this formulation incorporates a q-multiset multicover structure, we apply Bender's decomposition and exploit the max-flow min-cut theorem to derive an alternative formulation for the SPMMU that can be solved by constraint generation. To account for the uncertainties inherent to the forecasted patient demands at each demand origin, we consider a robust counterpart to the SPMMU by introducing uncertainty sets for both the steerable and unsteerable demand. For a specific choice of budgeted uncertainty sets, we obtain a linear formulation of the robust counterpart. By extending the separation problem of the deterministic case, we show how this formulation can be solved through constraint generation.

■ FA-10

Friday, 9:00-10:40 - ZEU/114/H

Financial Modeling II

Stream: Finance
Invited session
Chair: *Michael H. Breitner*

1 - An Optimal Compensation Mechanism in Modified Principal-Agent Model with Risk Aversion Concept

Tsai-ling Liu, Tyrone T. Lin

Abstract-The 2016 Nobel Memorial Prize in Economic Sciences was awarded to Professor Oliver Hart of Harvard University and Professor Bengt Robert Holmström of Massachusetts Institute of Technology in the U.S., both of whom are researchers of "Contract Theory". A contract is an important foundation for the operation of modern society, and how to design one more effectively given any conflicts of interest between two or more parties is an important subject in the related literature. Contract theory was originally applied in labor contracts and was called the "Principal-Agent Problem". This manuscript focuses to discuss how to establish a fair and optimal compensation mechanism between the principal (insurer) and agent (professional manager) in the Principal-Agent Model over a finite time period. This manuscript also targets how to properly integrate the impact of the overall revenue function attributable to professional managers' efforts based on the establishment of an insurer's compensation mechanism, along with the impact from the cost function relationship under the joint effects of managers' efforts. The main decision variable herein is defined by how the insurer and professional manager identify the balanced and optimal professional manager effort coefficient under the maximum expected utility in the context of risk aversion based on the satisfaction of their respective objective functions (utility functions generated by profit). This study incorporated the utility functions of HARA (Hyperbolic Absolute Risk Aversion) in the modified principal-agent model as the representative functions of their ultimate expected utility, so as to further identify the best professional manager effort parameter and fixed salary/variable bonus parameters under the decision parameters by optimizing the derivation and solution of the first-order conditions and second-order conditions for the problem. The results in this study offer a basis for establishing a fair and optimal compensation mechanism by the insurer. This study's main contributions include establishing and expanding the traditional Principal-Agent model into the context of risk aversion and to be a reference for the principal and

agent in respect of the fairness over compensation and performance rewards mechanism and their feasibility of application in general industries. Keyword: Principal-Agent Model, Risk Aversion, Effort, Fixed Salary, Variable Bonus, Hyperbolic Absolute Risk Aversion Acknowledgement: The authors would like to thank the Ministry of Science and Technology of the Republic of China, Taiwan for financially supporting this research under Contract No. MOST 107-2410-H-259 -013 -

2 - Measuring changes in Russian monetary policy: An index-based approach

Cornelia Sahling, Nikolay Nenovsky

Russia's transition to a market economy was accompanied by several monetary regime changes of the Bank of Russia (BoR) and even different policy goals. In this context we should mention the transformation of the exchange rate regime from managed floating (since 1999 and since 2005 with a dual-currency basket) to free floating (since November 2014). In the beginning of 2015 inflation targeting was introduced. However, since 2007 the BoR has declared price stability as primary goal of monetary policy. In addition, financial and currency crises (1998/1999, 2008/2009 and 2014/2015) occurred in Russia. The frequent changes in monetary policy patterns seem to complicate the estimation of policy in the case of Russia. Evidence from other investigations confirm this thesis. Vdovichenko/Voronina (2006) [1] conclude that for the period 1999-2003 a money-based rule is more suitable while Korhonen and Nuutilainen (2016) [2] consider the Taylor rule appropriate only for 2003-2015.

As a measurement of changes in Russian monetary policy we develop a Monetary policy index (MPI) for estimating changes in BoR policy. Our new MPI is motivated by Girardin et al. (2017) [3] who developed an index for measuring Chinese monetary policy. We focus on key monetary policy determinants for the Russian economy: capital inflows, inflation, oil prices, exchange rates, US and Eurozone interest rates developments and changing institutional environment and monetary policy regimes. The choice of key determinants is based on literature investigation considering Russian monetary policy and emerging countries' experience and, of course, official statements of the BoR.

Our investigation provides a practical contribution to the discussion of Russian monetary regimes by creating a new MPI adopted to the conditions in Russia. This research is also an attempt to make a theoretical contribution to the discussion of appropriate monetary policy regimes in transition countries and to provide empirical evidence for supporting our basic conclusions.

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3 - Where, when and how much to invest in a dynamic spatial structure under uncertainty? Agent-Based Modeling in a stable Cellular Automata.

Christoph Hentschel, Elmar Lukas

This research approach investigate the innovation diffusion as a stochastic simulation in a cellular automata. Agent-Based Modeling due to the work of Von Neumann (1940s) and his universal constructor as a self-replicating machine in a cellular automata has become a strong rising popularity for economic industries in the last few years. Simulation of innovation diffusion with deterministic agent-based modeling approaches is especially being used by firms to improve decision making. The most important model for the diffusion of innovations is the Bass Diffusion Model. The agent-based modelling theory based on cellular automata models. "The differences between the two models are due to the fact that time is continuous in the Bass Model but discrete in cellular automata models." (Fibich et.al., 2010) Starting with a research for relevant scientific literature about deterministic agent-based simulation approaches and a subsequent study of stochastic applications we want to model the innovation diffusion as a stochastic process with a view of spatial structure differences. Therefore Kiesling et.al. (2011) provides essential basics in a review and critical examination of the strengths and limitations of agent-based modeling. Lukas et. al. (2017) provides the Bass-Diffusion Model in extension with a stochastic implementation of a geometric Brownian Motion. In consideration of a map with local population differences, the diffusion rate of new innovative products can be different in spatial structures. Based on Conway's Game of Life (1970) as a simple two-dimensional cellular automata we start our research by a modification of this approach to a stable cellular automata with local differences in innovation diffusion. Regarding to the cash flow of uncertain investments in new innovative products and the consideration of local diffusion differences, decision-making should be improved.

References

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■ FA-11

Friday, 9:00-10:40 - ZEU/118/H

Last-Mile Delivery 2

Stream: Logistics and Freight Transportation
Invited session
Chair: *Tino Henke*

1 - Optimizing the changing locations of mobile parcel lockers in last-mile distribution

Stefan Schwerdfeger, Nils Boysen

To reduce congestion, environmental damage, and negative health impact in large urban areas plenty novel concepts for last-mile distribution have been innovated in the recent years. The concept treated in this talk is mobile parcel lockers that are able to change their locations during the day, either autonomously or moved by a human driver. By relocating lockers their reach towards addressees also varying their whereabouts over the day can be increased. The talk investigates the optimization of changing locations of lockers, such that customers are at some time during the planning horizon within a predefined range of their designated locker. The aim is to minimize the locker fleet when satisfying all customers. We formulate the resulting mobile locker location problem and provide suited exact solution procedures. To assess the potential whether mobile lockers are a promising last-mile concept, worth the investment required to develop it to a market-ready solution, we benchmark the necessary fleet size of mobile lockers with the required number of their stationary counterparts. Our results show that considerable reductions are possible.

2 - Impact of city center restriction policies for sustainable city logistics

Gerhard Hiermann, Richard Hartl, Jakob Puchinger, Maximilian Schiffer, Thibaut Vidal

Urbanization and the rapid growth of e-commerce yield increased delivery volumes in city centers, which increase congestion, noxious air pollution, and noise. Consequently, cities all around the world struggle with exceeded fine dust emission thresholds, especially in their centers. To this end, first municipalities apply restriction policies to reduce the number of internal combustion engine vehicles (ICEVs) from city centers. While such policies are well understood for passenger transportation, only little is known about their impact on logistic fleets. Against this background, we study the impact of city center restriction policies on a logistics service provider's fleet operations and its impact on emissions. We study three real-world case studies for the cities of Paris, Vienna, and New York City as well as five city center restriction policies: i) daily-fees, ii) per-entry fees, iii) distance-based fees, iv) time-based fees, and v) prohibiting ICEVs. To mimic the fleet operator's decision in daily operations, we developed a metaheuristic solution approach that incorporates a multigraph representation to account for trade-offs between time-shortest and cost-shortest paths. Our approach allows to consider a heterogeneous and mixed fleet of ICEVs and ECVs, time windows at customers and the possibility to recharge the battery if necessary. We show the varying impact of different pricing schemes and restriction policies. While some succeed in reducing traveled distance and emissions, others worsen the status quo.

3 - Optimization of last-mile delivery concepts for autonomous delivery robots

Stefan Schaudt, Uwe Clausen

With urbanization as an ongoing global trend increasing economic and transport activities are observable in cities world-wide. A still growing e-commerce keeps driving up the number of parcels to be delivered, especially in the B2C segment. Thus, the logistics industry is seeking new ways to increase efficiency and investigates new technologies for last-mile delivery. Some innovative concepts that have emerged in recent years are drones, autonomous vehicles, common economy, deliveries to the trunk of a car and parcel robots. Field tests for parcel delivery robots have been carried out all over the world. It turned out that for densely populated areas delivery robots are a promising alternative to traditional trucking. Delivery robots drive at walking speed on sidewalks and are equipped with the same technology used for autonomous vehicles. The capacity ranges between a single and multiple parcels depending on the model. These robots allow deliveries to commence upon receiving a request, helping to enhance customer satisfaction. Delivery robots can be used in a two-tiered concept, in which parcels are first transported by conventional trucking to a micro-depot, in the neighborhood of customers, and from there delivered with robots at customer's request. This leads to the following optimization problem, given a set of customers, delivery robots and micro-depots. Each customer has chosen a time slot, when to receive an ordered parcel. A robot has unit capacity. The goal is to start the robots such that the arrival time is closest as possible to the chosen time slot. We distinguish between two cases, in the first case the delivery robots are fixed assigned to the micro. In the second case, the assignment is flexible and each robot can change its assigned micro-depot after a delivery. An integer linear programming formulation is presented for both cases. Exact solutions are calculated and the running time is speeded up with the help of primal heuristics. The two concepts are tested and evaluated in a case study located in the city of Manhattan (USA).

4 - Dynamic Dispatching of a Heterogeneous Fleet in Urban Delivery

Jeannette A. L. Hermanns, Marlin Wolf Ulmer, Dirk Christian Mattfeld

This research analyzes the potential of heterogeneous fleets in urban delivery routing. Due to cost pressure, environmental restrictions, and workforce shortages, service providers recently test a variety of different vehicle types such as trucks, cargo bikes, or even autonomous delivery vehicles. The vehicle types differ in several dimensions, for example, daily operational costs, capacity, or range but also in (area-dependent) times required for traveling, parking, and delivering. In the considered problem, we utilize such a given heterogeneous fleet for serving dynamically requesting customers in the city. Each customer expects delivery from a depot before a deadline. Either we can serve a customer with our own vehicles, or, we need to outsource the delivery to an expensive third party. Our objective is to utilize the fleet efficiently and to minimize the third party costs. We present a heuristic method that exploits the individual strengths of the vehicles. Specifically, we identify features that indicate good matches between customers to vehicles. The features base on customer, vehicle, and routing attributes. We use the indicators to determine matchings between customers and vehicles. We pair this method with anticipation to estimate the flexibility of a matching decision with respect to future services. Results indicate that both matching and anticipation provide significant improvements compared to a reactive strategy.

■ FA-12

Friday, 9:00-10:40 - ZEU/146/Z

Robustness

Stream: Optimization under Uncertainty
Invited session
Chair: *Maciej Drwal*

1 - Mixed Uncertainty Sets for Robust Optimization

Marc Goerigk, Trivikram Dokka, Rahul Roy

In robust optimization, the uncertainty set is used to model all possible outcomes of uncertain parameters. In the classic setting, one assumes that this set is provided by the decision maker based on the data available to her. Only recently it has been recognized that the process of building useful uncertainty sets is in itself a challenging task that requires mathematical support.

In this presentation, we propose an approach to go beyond the classic setting, by assuming multiple uncertainty sets to be prepared, each with a weight showing the degree of belief that the set is a "true" model of uncertainty. We consider theoretical aspects of this approach and show that it is as easy to model as the classic setting. In a computational study using a shortest path problem based on real-world data, we autotune uncertainty sets to the available data, and show that with regard to out-of-sample performance, the combination of multiple sets can give better results than each set on its own.

2 - Robust Multistage Optimization with Decision-Dependent Uncertainty

Michael Hartisch, Ulf Lorenz

Quantified integer (linear) programs (QIP) are integer linear programs with variables being either existentially or universally quantified. They can be interpreted as two-person zero-sum games between an existential and a universal player on the one side, or multistage optimization problems under uncertainty on the other side. Solutions are so called winning strategies for the existential player that specify how to react on moves - certain fixations of universally quantified variables - of the universal player to certainly win the game. In this setting the existential player must ensure the fulfillment of a system of linear constraints, while the universal variables can range within given intervals, trying to make the fulfillment impossible. Recently, this approach was extended by adding a linear constraint system the universal player must obey. Consequently, existential and universal variable assignments in early decision stages now can restrain possible universal variable assignments later on and vice versa resulting in a multistage optimization problem with decision-dependent uncertainty. We present an attenuated variant, which instead of an NP-complete decision problem allows a polynomial-time decision on the legality of a move. Its usability is motivated by several examples.

3 - Solving robust two-stage combinatorial optimization problems under convex uncertainty

Adam Kasperski, Marc Goerigk, Pawel Zielinski

In combinatorial optimization problems a feasible solution is composed of some elements from a given element set. Each element has a nonnegative cost and we seek a solution with the minimum total cost. An important example is the class of network problems, in which we wish to compute a shortest path, a minimum spanning tree, a minimum assignment etc. in a given network G. In many practical applications a feasible solution can be constructed in two-stages. The current, first-stage costs are known exactly, while the future second-stage costs are uncertain and are only known to belong to a given uncertainty (scenario) set. We assume that this uncertainty set is convex, for example it is of a polyhedral or ellipsoidal type. In the two-stage approach, a part of feasible solution is constructed in the first stage and it is completed in the second stage after the true second-stage cost scenario is revealed. Using the robust framework, we seek a solution minimizing the total first and second-stage cost under the worst second-stage scenario realization. The resulting optimization problem is a three level min-max-min one and can be hard to solve. In this talk, the complexity status of basic problems under various uncertainty sets is presented. An exact algorithm for the robust two-stage problems, based on a row and column generation technique is shown. Additionally, some algorithms providing approximate solutions are also proposed. The results of computational tests for particular problems are presented.

4 - Robust Approach to Restricted Items Selection Problem

Maciej Drwal

In this paper we consider the robust version of the items selection problem, in which the goal is to choose representatives from a family of sets, preserving constraints on the allowed items' combinations. We prove NP-hardness of the general deterministic version, as well as establish polynomially solvable special cases. Next, we consider the robust version in which we aim at minimizing the maximum regret of the solution under interval parameter uncertainty. We develop an exact algorithm based on cut generation for the problem and present the results of computational experiments.

■ FA-13

Friday, 9:00-10:40 - ZEU/147/Z

Operational Planning and Stochastic Simulation III

Stream: Simulation and Statistical Modelling
Invited session
Chair: *Markus Günther*

1 - Predictive Analytics in Aviation Management: Passenger Arrival Prediction
Maximilian Moll, Thomas Berg, Simon Ewers, M. Schmidt

Due to increasing passenger and flight numbers, airports need to plan and schedule carefully to avoid wasting their resources, but also congestions and missed flights. In this paper, we present a deep learning framework for predicting the number of passenger arriving at an airport within a 15-minute interval. To this end, a first neural network predicts the number of passengers on a given flight. These results are then being used with a second neural network to predict the number of passengers in each interval. As we will demonstrate, the results of our approach is comparable to the ones obtained by a laborious, manual prediction.

2 - Simulation Based Capacity Planning of Police Forces
Kai Hoth, Tobias Cors, Malte Fliedner, Knut Haase, Martin Tschöke

In the planning of police forces an adequate allocation of resources to districts is crucial for providing an effective and robust service and for maintaining acceptable emergency response times. Due to the high operational heterogeneity and variability, determining reliable profiles for resource utilization and establishing their relationship to response times is a challenging task in and of itself that requires an adequate consideration of several sources of stochastic influence. Based on an extensive dataset comprising more than two million items, we estimate stochastic process models for all relevant police operations in a major metropolitan area and use a discrete-event simulation to analyze capacity utilization of a given fleet of police vehicles. The simulation model predicts the spatial and temporal occurrence of police operations and dispatches available vehicles from different districts, in order to model resource sharing in emergency response. The vehicle allocation is then optimized via a rule-based heuristic, observing shift patterns and local demand structure, until response time expectations are met. We provide preliminary experimental results and draw implications with respect to current capacities and future utilization.

3 - Simulation-based Optimization of order picking in the distribution center of a supermarket chain
Katrin Hügel

An interesting trend concerning the structure of supermarket stores is observed: after an age of consolidation, in which many small stores were replaced by few “megastores” opening on the greenfield, supermarket chains are now entering the market of kiosks, defined as small stores with extended opening hours, located at railway stations. This development poses additional logistic challenges for the supermarket chains. These very small stores place orders with many different articles, yet small volumes per article. In addition, these stores have to be delivered often due to minor warehouse capacities and they have to deal with a volatile demand. In this talk we present a decision support tool, developed for a large regional distribution center of a Swiss supermarket chain. Currently, they are responsible for supplying more than 100 stores, some of them with multiple deliveries per days. Most of the pallets shipped to the stores are assembled by an Automated Order Picking System, consisting of conveyer belts, overhead travel cranes, storage areas and articulated robots. A minority of pallets is built manually, since articles which are contained in boxes do not allow for handling by cranes and robots. Moreover the manual assembly is flexible, which becomes relevant, when the capacity of the Automated Order Picking Systemis insufficient. The distribution center handles over 20,000 crates and boxes per day. Typically, crates stay in the warehouse for only a few hours. In this project we optimize the assembly process by assigning ordered articles to the two production paths, ensuring the pallets can be shipped on time and total costs are minimized. The system is modeled as a queuing network where homogeneous pallets from food suppliers enter the system and heterogeneous pallets ordered by the stores leave the system. We apply discrete event simulation, where storage areas around the overhead travel cranes provide the decoupling point between push-forward logic and pull logic. Optimal allocation of crates over all available production paths (automatic or manual order picking) will be obtained via simulation-based optimization. The main challenge in this project is to appropriately model the process logic of overhead cranes and articulated robots. Their behavior is not only poorly documented, but also hard to derive from sensor measurements. Even video recordings or observations are insufficient. In this talk we compare the results obtained from our simulation-based optimization approach with the results obtained by experienced human production planners and discuss the challenges related to validating and calibrating our models. We conclude with an outlook on applications of our operational decision support tool for tactical and strategic planning at the distribution center.

4 - Modeling consumer heterogeneity matters: Computational experiments with an agent-based market simulation
Markus Günther, Christian Stummer

Adoption and diffusion of new products is a field of research that is of high practical relevance. In his seminal work half a century ago, Bass proposed a simple model describing innovation adoption among consumers as a differential equation in which consumers' average degree of innovativeness p and their average degree of imitation q (i.e., susceptibility to group pressure) are taken into account. More recently, agent-based simulation approaches have become popular in this field because many consumer markets exhibit typical properties of complex systems, that is, they are inherently intricate and they are predisposed to unexpected, sometimes even counterintuitive, outcomes as a result of numerous interactions of consumers among themselves and with their environment. Prior works have investigated various effects of exogenous variables such as conducting marketing measures and/or of market characteristics such as the density of the consumers' social network. In this work, we study the impact of consumer heterogeneity. As suggested by Bonabeau, we assume that averaging consumer characteristics might yield less rich results because aggregate differential equations tend to smooth out fluctuations whereas in more realistic market models with heterogeneous consumers, under certain conditions, fluctuations can be amplified. In other words, by averaging consumer characteristics the more extreme (and also more interesting) simulation results will not occur which is a loss for both researchers and practitioners. Furthermore, we assume that this effect is reinforced when considering that consumer agents who are similar in their personality are interconnected in the social network with a higher probability (motivated by the old adage of "birds of a feather flock together") and thus interact with each other more often. To test the above two hypotheses in a computational experiment, we first reimplemented the Bass model as an agent-based simulation approach. In doing so, we followed the lead of Rand and Rust who have thoroughly validated their model by comparing simulation results with the outcomes reported by Bass and colleagues in several application cases. In a second step, we set up a generic market and ran the simulation for two settings. In the first setting, all consumer agents have the same personality (i.e., they have identical parameter values for p and q) whereas in the second setting consumer agents differ in this respect (but still the average over all agents equals the values for p and q used in the first setting). In a third step, we finally reconfigured the social network by taking into account similarity of consumers' personalities (while, of course, network attributes such as the density remain the same). In our talk, we present the experimental setting and discuss our findings.

■ FA-14

Friday, 9:00-10:40 - ZEU/148/U

Game Theory and Experimental Economics II

Stream: Game Theory and Experimental Economics
Invited session
Chair: *Andreas Fügener*

1 - Delegation Between Humans and AI: An Experimental Investigation of the Future of Work
Andreas Fügener

A defining question of our age is how AI will influence the workplace of the future and, thereby, the human condition. The dominant perspective is that the competition between AI and humans will be won by either humans or machines. We argue that the future workplace may not belong exclusively to humans or machines. Instead, it is better to

use AI together with humans by combining their unique characteristics and abilities. In three experimental studies, we let humans and a state of the art AI classify images alone and together. As expected, the AI outperforms humans. Humans could improve by delegating to the AI, but this combined effort still does not outperform AI itself. The most effective scenario was inversion, where the AI delegated to a human when it was uncertain. Humans could in theory outperform all other configurations if they delegated effectively to the AI, but they did not. Human delegation suffered from wrong self-assessment and lack of strategy. We show that humans are even bad at delegating if they put effort in delegating well; the reason being that despite their best intentions, their perception of task difficulty is often not aligned with the real task difficulty if the image is hard. Humans did not know what they did not know. Because of this, they do not delegate the right images to the AI. This result is novel and important for human-AI collaboration at the workplace. We believe it has broad implications for the future of work, the design of decision support systems, and management education in the age of AI.

2 - Contracting in supply chains: a choice-based optimization approach
Nils Roemer, Guido Voigt, Sven Müller

We consider a supplier-buyer supply chain. The buyer holds private forecast information (high/low). The supplier offers a non-linear capacity reservation contract in order to align incentives. When all parties act rational and the utility of the contract receiving party is common knowledge, the revelation principle stipulates that one contract for each buyer type (high/low) supports the second-best outcome. We analyze how the number of contracts differs when lifting the rationality and/or common knowledge assumption in our choice-based optimization approach. Therefore, we use a mixed integer program to select contracts in combination with a multinomial logit model to describe the choice behavior of the buyer. Since very small choice probabilities cause numerical instabilities, we run a numerical study to analyze the limits of our approach.

3 - Demand Promotion or Forecasting? A Behavioral Study of How Contracts Influence Demand Effort Investment
Jose Benedicto Duhaylongsod, Yingshuai Zhao, Ulrich Thonemann

This paper studies a setting where a supplier sells to a retailer who can improve the quality of her demand information by investing costly demand-shaping effort. The retailer can either invest marketing effort to increase the mean of the demand (e.g., conduct promotions) or operations effort to reduce the variance (e.g., improve forecasting technology). In such a setting, the use of supply chain contracts can provide incentives to influence the retailer's investment decision and elicit information obtained by these investments to better inform inventory decisions. We focus on the role that supply chain contracts has on the retailers' preference for a particular type of effort investment that maximizes their profits. We first derive the conditions under which a retailer chooses a particular effort investment under a wholesale price contract and two other coordinating contracts. Next, in a controlled laboratory experiment, we test our predictions and evaluate the performance of these contracts in eliciting the optimal effort investment.

4 - Different perceptions of complexity: Human vs. AI approaches to the NIM game
Maximilian Moll, Ingo Althofer, Stefan Wolfgang Pickl

Recent years have seen incredible progress in Reinforcement Learning, particularly in highly complex games like Go and Chess. AlphaZero, for example, made the step from an expert knowledge informed starting point for training to learning expert play from just self-play. As impressive as this is, it is very hard to gain some insights into the inner workings due to the high complexity. In this paper we therefore turn to the simpler NIM game. The interesting point here is, that the human player has a quite easy solution strategy relying on binary addition without carries. We examine the learning behaviour based on expert knowledge as well as by self-play. These are then compared and contrasted with the human approach.

■ FA-15

Friday, 9:00-10:40 - ZEU/160/H

Advances in Linear and Integer Programming

Stream: Discrete and Integer Optimization
Invited session
Chair: *Stefan Ruzika*

1 - Strong IP Formulations Need Large Coefficients
Christopher Hojny

The development of practically well-behaving integer programming formulations is an important aspect of solving linear optimization problems over a set of binary points. In practice, one is often interested in integer formulations with additional properties, e.g., bounded coefficients to avoid numerical instabilities or a certain guarantee of strength, which are conflicting targets. In this talk, we investigate the interplay between strength and the size of coefficients.

To measure the strength of an integer formulation, we introduce the concept of 1/lambda-relaxations. 1/lambda-relaxations generalize classical integer formulations to refinements of the integer lattice by a factor of 1/lambda. After pointing out basic properties of 1/lambda-relaxations, we present a lower bound on the size of coefficients in any 1/lambda-relaxation of a binary set. Using this bound, we show that strong integer formulations with coefficients of constant size do not exist in general. In particular, we demonstrate that exponentially large coefficients may be necessary in any strong integer formulation.

2 - A Dissection of the Duality Gap of Set Covering Problems.
Uledi Ngulo, Torbjörn Larsson, Nils-Hassan Quttineh

Set covering problems are well-studied and have many applications, for example in vehicle routing. Sometimes the duality gap is significant and the problem is computationally challenging. We dissect the duality gap with the purpose of better understanding its relationship to problem characteristics, such as problem shape and density. The means for doing this is a set of global optimality conditions for discrete optimization problems. These decompose the duality gap into two terms: near-optimality in a Lagrangian relaxation and near-complementarity. We analyse these terms for numerous instances of large size, including some real-life instances. We conclude that when the duality gap is large, typically the near-complementarity term is large and the near-optimality term is very small. The large violation of complementarity is due to extensive over-coverage. Our observations should have implications for the design of solution methods, and especially for the design of core problems.

3 - Computing Prices in Product-Mix Auctions with Strong Substitutes
Maximilian Fichtl, Martin Bichler

We develop an efficient algorithm to find Walrasian equilibrium prices multi-unit, multi-item product mix-auctions in which participants express strong-substitutes preferences. Our algorithms are based on DC programming, where the difference of two convex functions is minimized. We develop a DC algorithm to find global optima necessary for Walrasian prices in the product-mix auction and show that the problem is dual to minimizing the Lyapunov function.

4 - An FPTAS for a General Class of Parametric Optimization Problems
Stefan Ruzika, Arne Herzel, Cristina Bazgan, Clemens Thielen, Daniel Vanderpooten

In a (linear) parametric optimization problem, the objective value of each feasible solution is an affine function of a real-valued parameter and one is interested in computing a solution for each possible value of the parameter. For many important parametric optimization problems including the parametric versions of the shortest path problem, the assignment problem, and the minimum cost flow problem, however, the piecewise linear function mapping the parameter to the optimal objective value of the corresponding non-parametric instance (the optimal value function) can have super-polynomially many breakpoints (points of slope change). This implies that any optimal algorithm for such a problem must output a super-polynomial number of solutions.

We provide a (parametric) fully-polynomial time approximation scheme for a general class of parametric optimization problems for

which (i) the parameter varies on the nonnegative real line, (ii) the non-parametric problem is solvable in polynomial time, and (iii) the slopes and intercepts of the value functions of the feasible solutions are nonnegative, integer values below a polynomial-time computable upper bound. In particular, under mild assumptions, we obtain the first parametric FPTAS for each of the specific problems mentioned above.

■ FA-16

Friday, 9:00-10:40 - ZEU/250/Z

Advances in Optimal Control

Stream: Control Theory and Continuous Optimization
Invited session

Chair: *Gerhard-Wilhelm Weber*
Chair: *Andrea Seidl*

1 - History-dependence in a bi-objective capital accumulation problem

Andrea Seidl, Richard Hartl, Peter Kort

We consider the problem of a firm which decides about investing into a capital stock needed for production. On the one hand the firm wants to maximize revenues, on the other hand it wants to minimize emissions which are caused by production. To handle the conflicting objectives, we apply the epsilon-constraint method. We sequentially solve the optimal control problem numerically for the first objective with the constraint that the second objective must be lower than its value from the previous step minus a constant. In this manner we calculate the Pareto front for different initial state values.

We analyze the impact of multiple objectives on the optimal solution path and determine a threshold curve which separates areas on the Pareto front differing with respect to the long-run steady state which is approached.

2 - Accumulation and Obsolescence of Human Capital

Andreas Novak, Gustav Feichtinger

The main purpose of McDowell's (1982) analysis was to study the impact of obsolescence of knowledge on research productivity over a career. For that he studied how the investment behavior of individuals in their human capital changes with the rate at which the knowledge depreciates over time. The main results of the following 'variant' of McDowell's life cycle model is that his results remain valid for a correct use of the human capital stock in Ben-Porath's style. In particular, we are able to show that the optimal production of human capital depends negatively on the obsolescence rate and that this reduction is largest at the early ages.

3 - Deep Learning and Model Predictive Control for a Flow Control Problem

Katharina Bieker

As the complexity of technical systems is increasing, controlling the latter becomes more and more challenging, particularly if the system dynamics are described by nonlinear partial differential equations (PDEs). In order to control these systems, machine learning based approaches have recently been proposed. Here, surrogate models of the underlying physics (or - alternatively - the control relevant dynamics) are inferred, based on which robust feedback controllers can be constructed. In this talk, we consider a combination of a deep learning (DL) architecture and model predictive control (MPC). In an MPC approach, a model is used to predict the system behavior over a finite time horizon. Based on these predictions, an optimal input can be computed by solving an open loop optimal control problem. In our approach, the open loop problem is replaced by a Deep Neural Network which directly predicts the optimal control input for a given system and reference state. The proposed method is then applied to the flow around three cylinders (the fluidic pinball) which is governed by the 2D incompressible Navier-Stokes equations. The aim of our DL-MPC approach is to control the system in such a way that the lift of each cylinder follows a given trajectory.

4 - A robust optimal control approach to management of defined contribution pension funds

Gerhard-Wilhelm Weber, Ioannis Baltas, Athanasios Yannacopoulos, Marek Szczepanski, Krzysztof Kolodziejczyk, Lukasz Dopierala

The aim of the present work is to study the problem of optimal management of defined contribution pension funds within a model uncertainty framework (to the best of our knowledge, this is among the first works to study this problem). To be more precise, we consider a fund manager who is endowed with some initial wealth and her role is to optimally distribute the fund's wealth among several financial assets. In this work, we assume that the fund manager has the possibility to invest part of the fund's wealth in a market consisting of two risky assets (zero coupon bond and stock) and a bank account. Within this framework, model uncertainty aspects are introduced as the fund manager does not fully trust the model she faces; hence she decides to make her decision robust. By employing robust control and dynamic programming techniques, we provide closed form solutions for the case of the exponential utility function. Moreover, we provide a detailed study of the limiting behavior of the associated stochastic differential game. Finally, we present a novel numerical approach that elucidates the effect of robustness on the optimal investment decisions of the fund manager.

■ FA-17

Friday, 9:00-10:40 - ZEU/255/Z

Multiple Criteria Decision Making

Stream: Decision Theory and Multiple Criteria Decision Making
Invited session

Chair: *Christina Scharpenberg*
Chair: *Tobias Witt*

1 - Combining scenario planning, energy system analysis, and multi-criteria analysis to develop and evaluate energy scenarios

Tobias Witt, Jutta Geldermann

The energy system transformation toward energy from renewable sources poses future challenges for the energy supply. In this context, making rational decisions today requires planning ahead and investigating possible transition pathways with energy scenarios. Scenario planning, energy system analysis, and multi-criteria analysis can be applied to support the development and evaluation of energy scenarios. All of these methods have unique processes and terminologies and model uncertainty in different ways. For an integrated development and evaluation of energy scenarios, based on scenario planning, energy system analyses, and multi-criteria analysis, however, it is important that the concept of uncertainty be used consistently. Therefore, a framework that combines the three methods is required. We develop this framework from the standard procedures of scenario planning, energy system analysis, and multi-criteria analysis. We illustrate and evaluate this framework using a case study that investigates the transition of the electricity sector in Lower Saxony, Germany, toward energy from renewable sources. Although the required efforts for coordination and modeling within this framework are higher, the framework increases the transparency of the decision support. The results of our case study suggest that the main benefits of the framework are a shared perception of the decision problem and a clarification of the use of terminology.

2 - Assessment of energy and emission reducing measures in container terminals using PROMETHEE

Erik Pohl, Christina Scharpenberg, Jutta Geldermann

While serving as an interface of sea and land-side, container terminals play an important role in global supply chains. The operators of container terminals, on the one hand, are facing pressure on maintaining or even getting a higher level of throughput by shipping companies, on the other hand, port-authorities and governments put pressure on energy saving and emission reduction. Therefore, the goal of many container terminals today is to reduce energy consumption while maintaining or improving the current service level. Since most of the energy of container terminals is needed for container handling equipment, emissions can be reduced by using clean energy or by replacing old equipment with energy-saving devices. The project "Simulation-based evaluation of measures for the improvement of energy sustainability in port operations" (SuStEnergyPort), carried out by the University Duisburg-Essen and the Hamburg Port Consulting GmbH (HPC) aims at developing a structured, model-based methodology to identify suitable measures that port operators can use to improve their energy efficiency and utilization of renewable energy. In this project, a selection of promising measures for the abatement of CO2 emissions is implemented in a

simulation tool covering both logistic and energetic aspects. As some measures include using new container handling equipment, e.g. straddle carrier, a Life Cycle Assessment (LCA) is used to measure and compare the environmental impact. In this talk, we analyze and evaluate different energy consumption and emission reduction measures applicable to container terminals using PROMETHEE. The assessment is based on data derived from the projects case study, the container terminal Tollerort (CTT) in Hamburg, and the simulation tool. We consider ecological, economic and social criteria and analyze the trade-off between energy or emission saving and service levels. The SIMOS method is used to determine the weights of the criteria for multiple stakeholders of the container terminals, e.g. operators and port-authorities. On the basis of this assessment, a roadmap towards a more profitable and ecological port operation can be developed.

3 - Prioritizing Cosmetics Brands' Websites Evaluation Criteria by Using Pythagorean Fuzzy AHP
Betül Özkan

Cosmetics industry is one of the most growing sectors in business. With the increase of e-commerce activities worlwide, many cosmetics brands have started their online websites. Cosmetics products are used on the skin so they are related to healthcare and and cosmetic products have shelf life. For that reason it is very important to have high quality and cosmetics brands online websites should pay extra attention to the quality of products to meet customers' satisfaction. Different factors affect the customers' choices when deciding from which cosmetics' brand website they will shop and there are also some specific factors for cosmetics products to consider, so assesing these factor can be evaluated as a multi criteria decision making (MCDM) problem. In this study, these criteria are prioritized by using Pythagorean fuzzy Analytic Hierarchy Process (AHP). Pythagorean fuzzy sets are used to handle better with uncertainty. 4 main criteria and 14 sub-criteria are determined for evaluation and they are ranked according to their importance. The results will help to identify which criteria are more important to improve the quality of the cosmetics brands websites.

4 - Examining the sustainability frontier of 63 provinces in Vietnam via families' positive value chain
Minh Hanh Le

Vietnam has been a dynamic economy in the world during the past fifteen years and currently being in the top three fastest growing economies in Asia (Asian Development Bank 2018). In such a long ride, now is the high time to have a close look at how life of people has been improved across the country. The present research is developed from a household perspective and aims to explore which provinces in Vietnam are the best to live for families. All 63 provinces of Vietnam are assessed based upon a chain of positive values towards families. The design of value chain centers around the notion of capabilities as core of families' quality of life. Following Armatya Sen (2009), the well-being of families are judged based on their capabilities to do things they have reason to value, stressing their freedom of choice. Network Data Envelopment Analysis models can effectively facilitate the assessment along the value chain. As a result, the provinces are benchmarked against the knowledge resource creating efficiency, commodity efficiency, capability efficiency and attainment efficiency. From the theoretical aspect, the research proposes a new measure of provincial performance that takes into account the household perspectives and their value chain. From the practical aspect, rankings of provinces provide very good information for planning at provincial government level and resource allocation at state government level.

■ FA-18

Friday, 9:00-10:40 - ZEU/260/H

Procurement

Stream: Supply Chain Management
Invited session
Chair: *Marcus Brandenburg*

1 - A set-covering model and a heuristic solution approach for multi-criteria supplier selection under consideration of risk and cost
Marcus Brandenburg

Supplier selection is a complex and decisive task of strategic supply chain management. When compiling the supplier pool, conflictive risk and performance aspects need to be taken into account. In particular, cost for managing the relations to suppliers need to be considered as well as the risk of supplier breakdown and resulting supply disruptions. A small and streamlined pool of suppliers that may result from a single sourcing strategy causes lower costs but increases the risk of major supply stoppages. Broadening the supplier pool, e.g. by integrating backup suppliers or following a multiple sourcing strategy, helps mitigating the supply risk but increases the resulting network cost. Most prominent decision-making techniques for supplier selection comprise MCDM, mathematical programming and artificial intelligence. In this study, a set-covering problem formulation is chosen to model the supplier selection problem. Greedy heuristic approaches are applied to solve the formulated problem and numerically tested at generic test instances.

2 - Backup sourcing in newsvendor models with unreliable suppliers
Dimitrios Pandelis, Ioannis Papachristos

We study newsvendor models with primary suppliers that are subject to random yield and a reliable backup supplier whose capacity is reserved by paying a premium. At first the retailer decides on the amounts to be ordered from the primary suppliers and to be reserved from the backup supplier. Then, the retailer may exercise the option to buy any amount up to the reserved capacity after the quantities from the primary supplies are delivered. We consider separately the cases when the option to buy from the backup supplier is exercised before or after the demand becomes known as well. For both models we present numerical results that provide interesting insights into the effect of various model parameters on the optimal order and reservation quantities.

3 - Decision Support for Material Procurement
Heiner Ackermann, Erik Diessel, Michael Helmling, Christoph Hertrich, Neil Jami, Johanna Schneider

Manufacturers spend significant portions of their turnover on raw materials and intermediate products. In order to be able to purchase these reliably and cheaply, they qualify suitable suppliers and conclude long-term framework agreements with them. Within the framework of these contracts, they periodically order the required quantities for the next production period. The producers thereby try to minimize the total costs by exploiting the leeway within the contracts. Total costs include material prices and transport costs as well as import duties.

From a mathematical point of view, this allocation problem can first be described as a min-cost flow problem in a bipartite, time-expanded graph. In contrast to the standard formulation of the min-cost flow problem, additional aspects have to be considered:

- Capacity and volume conditions set upper and lower bounds to the order quantities. - Some suppliers constantly produce material above or below specification. This can partially be compensated by adjusting the amounts used for those materials. To this end, more or less material may have to be purchased from them. - Sometimes it is partially possible to interchange one material by another one used at the same time. Considering these material interchanges can reduce purchasing costs. - Technical constraints restrict the maximum number of suppliers who may simultaneously supply a production site. - Suppliers grant multi-stage discounts when the order quantities exceed certain thresholds. - Suppliers impose penalties when order quantities fall below contracted thresholds. - In some cases, the producers also purchase the raw materials for their suppliers and ask them for processing. By applying this so-call second-level buying, further cost savings can be achieved by ordering larger quantities.

In this talk, we will present the allocation problem in detail and describe how the above-mentioned enhancements can be incorporated into the LP formulation of the basic min-cost flow problem. Some of them make the problem NP-hard and require considering integral constraints.

We also report how we have integrated the optimization process into a decision support system for the material purchasing of a globally operating manufacturer. Here, two questions are of particular interest: How to compare alternative allocations? How to balance between purchasing costs and the risk of material shortages due to supply failures?

Friday, 11:15-12:00

■ FB-02

Friday, 11:15-12:00 - POT/051/H

Semiplenary Presentation Olga Battaia

Stream: Semiplenary Presentations
Invited session
Chair: *Udo Buscher*

1 - Metamorphoses of scheduling and assignment problems
Olga Battaia

This talk will be dedicated to some well-known scheduling and assignment problems as "Bin packing", "Resource Constrained Project Scheduling" (RCPSP), "Simple Assembly Line Balancing" (SALBP), etc. Originally, these problems were formulated for a small number of assumptions and were quite distinct in their properties. For different reasons we can observe metamorphoses of these simple problems towards much more complex formulations with more and more constraints imposed by the different optimization contexts. These metamorphoses will be discussed in this talk.

■ FB-03

Friday, 11:15-12:00 - POT/081/H

Semiplenary Presentation Dolores Romero Morales

Stream: Semiplenary Presentations
Semi-plenary session
Chair: *Fabien Tricoire*

1 - Interpretability in Data Science matters and Mathematical Optimization can help
Dolores Romero Morales

Data Science aims to develop models that extract knowledge from complex data and represent it to aid Data Driven Decision Making. Mathematical Optimization has played a crucial role across the three main pillars of Data Science, namely Supervised Learning, Unsupervised Learning and Information Visualization. Nowadays, interpretability of Data Science tools matters, not only to regulators but to a wider set of users. In this presentation, we review recent Mixed-Integer NonLinear Programming models that enhance the interpretability of state-of-art data science tools.

■ FB-06

Friday, 11:15-12:00 - POT/151/H

Semiplenary Presentation Roberto Aringhieri

Stream: Semiplenary Presentations
Invited session
Chair: *Stefan Nickel*

1 - Online optimization in health care delivery: overview and possible applications
Roberto Aringhieri

TBA

Friday, 13:30-15:00

■ FC-03

Friday, 13:30-15:00 - POT/081/H

Plenary Presentation Claudia D'Ambrosio & Closing Ceremony

Stream: Plenary Presentations
Plenary session
Chair: *Rainer Lasch*

1 - On the Observability of Smart Grids and Related Optimization Methods
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. In this talk, we focus on a strategic problem in smart grids, the phasor measurement units placement. The aim is to make the grid observable, i.e., to install devices that can communicate the status of part of the grid. Being able to observe it allow the grid manager to improve efficiency. We introduce several equivalent formulations and discuss their advantages, drawbacks, and some tailored algorithms.

2 - Closing Ceremony
Jörn Schönberger

We will look back to OR2019 but also look forward to OR2020.

STREAMS

Business Analytics, Artificial Intelligence and Forecasting

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Track(s): 17

Control Theory and Continuous Optimization

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Decision Theory and Multiple Criteria Decision Making

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Discrete and Integer Optimization

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Logistics and Freight Transportation

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Optimization under Uncertainty

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Plenary Presentations

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Semiplenary Presentations

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Simulation and Statistical Modelling

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Software Applications and Modelling Systems

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