

Wednesday, 9:00-10:30

## ■ WA-27

Wednesday, 9:00-10:30 - HFB|Audimax

### Opening Ceremony and Plenary Lecture

Stream: Plenaries

*Plenary session*

Chair: *Natalia Kliewer*

Chair: *Ralf Borndörfer*

Chair: *Jan Fabian Ehmke*

#### 1 - Green Logistics: Decision Analytics for Sustainable Transportation

*Richard Eglese*

The environmental effects of transporting goods are of increasing concern to managers and policy makers. The use of fossil fuels, such as petrol and diesel oil, in transport produces air pollutants that can have a toxic effect on people and the environment. However, one of the main drivers for the concern over the environmental effects of freight transport has been the potential effects of the production of greenhouse gas (GHG) emissions on climate change from the use of carbon-based fuels.

Research into models for transportation and logistics has been active for many years. Much of the modelling has been with the aim of optimising economic objectives or improving measures of customer service. However, in recent years, more research has been undertaken where environmental objectives have also been considered, so that supply chain and other logistic services can be delivered in a more sustainable way.

For the OR analyst, there are many choices to be made about how to model freight transport operations. Can old models be revised with a simple change of objective or are more radical changes needed? We shall examine some of these choices and illustrate the issues with cases studies to show what contribution can be made to environmental and other objectives through the use of decision analytic models. This will include issues raised by the use of new technologies, such as the use of electric or other alternatively powered vehicles.

Wednesday, 11:00-12:30

## ■ WB-01

Wednesday, 11:00-12:30 - WGS|101

### Methods for Robustness

Stream: Optimization under Uncertainty

*Parallel session*

Chair: *Fabian Mies*

#### 1 - Choosing a set of solutions to hedge against the worst case

*André Chassein*

We investigate the concept of  $k$ -adaptability. The idea of the concept is to prepare a set of  $k$  solutions from which the best can be picked after the uncertain cost scenario has been revealed. Note that this is a generalization of the classic concept of robust optimization where one is allowed to choose only a single solution to prepare against the uncertain cost realizations. The new concept is inspired by adjustable robustness proposed by Ben-Tal et al. where one splits the variables in "here and now" and "wait and see" variables. We consider combinatorial optimization problems with bounded uncertainty sets which were proposed by Bertsimas and Sim. We focus on the two cases where  $k$  is fixed or  $k$  is equal to 2. First, we present a compact nonlinear reformulation of the problem by dualizing the adversary problem. Next, we show how to transform the nonlinear problem to polynomially many subproblems which can be formulated as mixed integer programs. Using this reformulation, we show how the 2-adaptability problem can be solved efficiently for the unconstrained combinatorial problem, the selection problem, and the minimum spanning tree problem. For the shortest path problem it turns out that the  $k$ -adaptability problem is NP-complete even for  $k$  equal to 2 but polynomial solvable if  $k$  is fixed and the underlying graph is restricted to be series parallel or to have bounded treewidth and bounded max degree. We prove that an approximation algorithm for the subproblem can be transferred to an approximation algorithm for the 2-adaptability problem. For the knapsack problem, we construct a PTAS for the subproblem resulting in a PTAS for the 2-adaptability problem. Further, we prove that no FPTAS can exist for the subproblem if P is not equal to NP.

#### 2 - Globalized Gamma-Robustness

*Andreas Börmann, Christina Büsing, Lena Maria Hupp, Frauke Liers, Manu Kapolke*

We extend the notion of "globalized robustness", introduced by Ben-Tal and Nemirovski, to the case of polyhedral Gamma-uncertainty-sets. The globalized robust counterpart to an uncertain linear program that is considered here allows for the immunization of the solution against Gamma-many changing parameters in a given row, as studied by Bertsimas and Sim. In addition, it allows to "smoothen" the behaviour of the solution for parameters outside of the prescribed Gamma-uncertainty-set. If more than the Gamma-many specified parameters change, or they change by more than was initially specified, the violation in the corresponding constraint or in the objective function will remain moderate, dampened by a suitable penalty term.

In this talk, we focus on the global robustification of the objective function, deriving compact linear formulations and complexity results. The tractability of our formulations and the quality of the obtained solutions will be tested for uncertain variants of several combinatorial optimization problems.

#### 3 - Blending robust and stochastic optimization of two-stage problems

*Fabian Mies, Britta Peis, Andreas Wierz*

Uncertainties in two-stage problems are typically described by either robust or stochastic models. The former aim to optimize the worst case performance of a solution, whereas the latter consider the expected cost with respect to some probability distribution. While the stochastic perspective allows for a greater modeling flexibility, it suffers from an increased model size since all possible scenarios need to be considered. On the other hand, robust models can often be generated adaptively by only considering relevant scenarios. In this talk, we present a flexible modeling framework to combine the advantages of

robust and stochastic optimization. By specifying the probability distribution of the uncertainty set only up to a given level of granularity, our method can be interpreted as to interpolate between a robust and a stochastic objective, containing both approaches at its extremes. We highlight that by restricting the supplied amount of information about the uncertainty, the suggested compromise is less susceptible to misspecification. In particular, if the probability distribution is estimated based on historical data, solutions are less prone to overfitting, as made precise by tighter risk bounds.

## ■ WB-02

Wednesday, 11:00-12:30 - WGS|102

### Modeling Systems I

Stream: Software Applications and Modelling Systems  
*Parallel session*

Chair: *Ingmar Steinzen*

Chair: *Jens Peter Kempkes*

#### 1 - Optimizing in the Cloud - Deploying Optimization Models on the Cloud with Web Services REST API's *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 soon-to-be-released MPL REST Server, which allows optimization models to be easily deployed on the cloud. By delivering optimization through a standard REST API, which accepts data in either JSON or XML formats, the optimization becomes purely data-driven. 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.

Google and Amazon have been among of the leading software vendors in the area of Web Services and publish several REST API's which can be quite useful for deploying optimization applications. On the server side, optimization models can easily access online data using for example the Google Sheets API and Amazon DynamoDB. On the client side, libraries such as the Google Maps API and the Google Visualization API can be used to provide rich user experience. We will be demonstrating mobile web applications which utilize the MPL REST Server and the Google/Amazon REST API's for deploying optimization models.

#### 2 - Cloud Strategies for Optimization Modeling Software *Robert Fourer*

Modeling languages and systems for optimization first appeared online 20 years ago – not long after web browsers came into widespread use – and have continued to evolve through the development of what came to be known as software as a service and cloud computing. In comparison to solver services that compute and return optimal solutions, cloud services for building optimization models and reporting results have proved especially challenging to design and deliver; a collaboration between local clients and remote servers often provides the best environment for model development. This presentation will start with the pioneering free NEOS Server, will compare more recent commercial offerings such as Gurobi's updated Instant Cloud, and will conclude with a description of the QuanDec service for creating web-based collaborative applications from AMPL models.

#### 3 - Solving routing and scheduling problems using LocalSolver *Julien Darlay*

LocalSolver is a heuristic solver for large-scale optimization problems. Having modeled your optimization problem using common mathematical operators, LocalSolver provides you with high-quality solutions in short running times. Combining different optimization techniques, LocalSolver scales up to millions of variables, running on basic computers. One of the strengths of LocalSolver is its rich yet simple modeling framework. Indeed, most usual mathematical operators are available, including arithmetical expressions (sum, product, trigonometric functions) or logical expressions (comparisons, conditional terms, array

indexing). As a consequence, there is no need to linearize the considered problem: the user can model it directly and naturally. Initially this modeling power was based on numerical decision variables only (binary, integer or continuous). A significant extension to this approach was brought in 2015 with the introduction of high level decision variables, inspired from "set-based variables" introduced in Constraint Programming. Many optimization problems involve sequencing or ordering concepts: scheduling, routing, network design. For these problems, a new type of variables yields even simpler and more compact models. The value of such a variable is not a number but a collection of numbers. More precisely, a list variable  $list(n)$  represents a sub-permutation of the set  $0,1,2,\dots,n-1$ . We will show in this presentation how this new kind of variables allows building very simple and very effective models for a number of optimization problems, including routing and scheduling problems.

#### 4 - OPTANO Modeling

*Jens Peter Kempkes, Lars Beckmann*

OPTANO Modeling, formerly known as Optimization.Framework, is a .NET Modeling API. During the past year we have put a lot of thought and work into supporting more modeling aspects, better documentation and support for even more solvers. It seamlessly integrates into applications, leads to testable models and can easily be used in continuous integration pipelines - in short: OPTANO Modeling is enterprise ready.

This talk will show recent advances of OPTANO Modeling and the OPTANO eco system. It will address both users and optimization software developers.

## ■ WB-03

Wednesday, 11:00-12:30 - WGS|103

### Location Planning

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: *Tim Kammann*

#### 1 - Multi-objective capacitated facility location problem: A case study of Tehran earthquake *Mahdi Shavarani*

Facility location problems are commonly used to select a predetermined number of facility locations among a set of potential locations. In this study, each candidate location is considered with a specific capacity and opening cost. It is supposed that the demand is uniformly distributed along the edges. A mathematical model is developed to minimize the aggregate costs for the construction of facilities, aggregate travel distance and unsatisfied demand. Since the network problems are NP-hard, a Non-dominated sorting genetic algorithm II (NS-GAII) is developed to solve the proposed model. The number of selected locations is a decision variable; thus an approach is proposed to deal with the changing length of the chromosomes. To demonstrate the applicability of the developed mathematical model, a case study is performed to find the best location of shelters in response to a major earthquake in Tehran.

#### 2 - 2-Echelon Optimization Model for Urban E-Grocery Operations

*Tim Kammann, Agathe Kleinschmidt, Sören Schindler, Max Leyerer, Marc-Oliver Sonneberg, Michael H. Breitner*

In this paper, we address an innovative business concept for e-grocery operations by using an urban network of refrigerated Foodstations. Regarding the last mile delivery, consumers collect orders by themselves or ordered goods are delivered by means of electric cargo bicycles. To determine the locations of the Foodstations and both the routes from the warehouse to the stations and the routes from the stations to the consumers, we propose a 2-echelon optimization model minimizing costs and traffic volume. We present a Location Routing Problem (LRP) and a rich variant of a Vehicle Routing Problem (VRP) considering multiple products, compartments, time windows, and a split delivery. With our approach, we contribute to the concept of e-grocery allowing for less pollution and a more sustainable city environment.

### 3 - Determining the influence of truck appointment systems at container terminals on truck arrival patterns of related logistics nodes

*Ann-Kathrin Lange, Anne Schwientek, Carlos Jahn*

Due to the increasing size of container ships, the related amount of containers to be handled for each ship in one port is growing as well. This leads to high peak situation for truck arrivals at logistics nodes and especially container terminals. In peak situations the gate and yard areas at container terminals are often strained to deal with the high amount of arriving trucks causing high costs for the terminals and long waiting times for the trucks. One much discussed method to mitigate the strain caused by peaks is to introduce a truck appointment system. The effects of this system on terminal performance and on truck waiting times have been analyzed widely in past studies with varying results. Other related logistics nodes in the port such as empty container depots, custom services or packing stations are rarely considered in spite of their importance for the port's efficiency and their role in drayage processes. To cover parts of this research gap, the focus of this paper is on the influence of truck appointment systems at container terminals on the truck arrival patterns of subsequent logistics nodes. A discrete event simulation model based on real-world data of the port of Hamburg is used to study the impact of different TAS' characteristics, e.g. the length of the time windows for each truck to pick up or drop of a container or the distribution of the time windows during the day, on the different actors involved in drayage processes in Hamburg. For the truck arrival patterns restricted opening hours of the logistics nodes and limited working times for the truck drivers are considered.

### ■ WB-04

*Wednesday, 11:00-12:30 - WGS|104*

#### Graphs and Complexity

Stream: Graphs and Networks  
*Parallel session*

Chair: *Stephan Schwartz*

#### 1 - A Graph Theoretic Approach to Solve Special Knapsack Problems in Polynomial Time

*Carolin Rehs, Frank Gurski*

The knapsack problem is a well-known NP-hard problem in combinatorial optimization. We introduce a graph theoretic approach in order to solve a large number of knapsack instances in polynomial time. For this purpose we apply threshold graphs, which have the useful property, that their independent sets correspond to feasible solutions in respective knapsack instances. Presenting a method to count and enumerate all maximal independent sets in a threshold graph in polynomial time and expanding this method for k-threshold graphs, allows to solve every knapsack instance with equivalent threshold graph as well as every multidimensional knapsack instance with equivalent k-threshold graph for fixed number of dimensions in polynomial time. Furthermore, our results improve existing solutions for the maximum independent set problem on k-threshold graphs.

#### 2 - The Graph Segmentation Problem

*Stephan Schwartz, Leonardo Balestrieri, Ralf Borndörfer*

We study a novel graph theoretical problem arising in the automatic billing of a toll network. The graph segmentation problem (GSP) is to cover a family of user paths in a given network with a set of disjoint segments (which are also paths). We investigate structural properties of the problem and derive tight bounds for the utility of an optimal segmentation. While the GSP is NP-hard in general, special cases can be solved in polynomial time. We also give an integer programming formulation that benefits from the results of our structural analysis. Computational results for real-world instances show that in practice the problem is more amenable than the theoretic bounds suggest.

### ■ WB-05

*Wednesday, 11:00-12:30 - WGS|104a*

#### Location of Charging Stations for Electric Vehicles

Stream: Traffic, Mobility and Passenger Transportation  
*Parallel session*

Chair: *Brita Rohrbeck*

#### 1 - Decision Support for Location Planning of Electric Vehicle Recharging Infrastructure

*Paul Göpfert, Stefan Bock*

To leverage the adoption of electric vehicles for day-to-day use is one of the main aims of contemporary environmental politics. But the usefulness of electric vehicles is limited as long as an adequate recharging infrastructure is missing. Without the possibility to recharge on the way, people usually do not consider electric vehicles for traveling on long distance relations.

In this talk we consider a decision support system for a recharging infrastructure provider in order to facilitate the creation of an efficient network of recharging stations for long distance traveling. The underlying optimization problem is based on the routing and refueling location model (Yildiz et. al. 2016). We propose heuristic filtering rules making the set of possible stations small enough to apply relaxations of exact approaches for the aforementioned model. Furthermore, the performance of simple insertion heuristics as well as a tabu search approach is tested on a realistically sized network for the federal republic of Germany.

#### 2 - Location Planning of E-Taxi Charging Stations

*Gregor Godbersen, Rainer Kolisch*

We are considering the problem of allocating charging stations to cater a fleet of electric taxis in a metropolitan area. Despite recent work on allocation of charging stations for private e-cars, this problem has not been fully treated in the literature. Unique aspects are high mileages and 24-hour shifts with short breaks which ask for broader coverage of charging stations. We model the problem as mixed-integer program (MIP) optimizing charging infrastructure investment costs. Since the MIP cannot be solved for large real-world instances, we present an adaptive large neighborhood heuristic. Experimental results and managerial insight for a real-world data set from a German metropolitan area with 1.5 million inhabitants are presented.

#### 3 - Location Planning of Charging Stations for Electric City Buses Considering Battery Ageing Effects

*Brita Rohrbeck, Kilian Berthold, Felix Hettich*

In the context of global warming and effective energy usage, electrification of traffic is one important pillar of forward-looking behaviour. This affects not only private cars, but also freight vehicles as well as public transportation, hence buses. A cost-minimal network configuration for electric city buses, including battery ageing effects, is the focus of this presentation.

Electric city buses with stationary charging technology follow the trend of sustainable technologies and unburden cities from greenhouse gases and noise emissions. However, their technology and charging infrastructure is still costly, and a cost-optimal solution strongly depends on the batteries' capacities as well as on the number and locations of charging stations. The capacity of a battery is again greatly influenced by ageing effects due to time and usage. The objective is to find a set of locations for the charging stations that keeps the overall costs minimal.

In our talk we discuss the parameters influencing the battery performance and deduce a capacity decay function to incorporate the impact of battery ageing. We introduce a mixed integer model with multiple periods that gives a cost-optimal solution. We enhance the model by a battery ageing function and extend it towards a network of bus lines.

We give an overview of our results obtained from real world data of the bus network of Mannheim. To prove the quality of our solutions, we contrast them with the present configuration used in Mannheim and analyse them within the framework of a simulation.

## ■ WB-06

Wednesday, 11:00-12:30 - WGS|105

### Graphs and Modeling Techniques

Stream: Graphs and Networks

Parallel session

Chair: Jonas Schweiger

#### 1 - Atherosclerosis development as a complex biological phenomenon studied using Petri nets

*Kaja Chmielewska, Dorota Formanowicz, Piotr Formanowicz*

Atherosclerosis is a very complex issue and the use of Petri nets for its modeling and analysis allows to systematize existing knowledge about this phenomenon and for new discoveries. This is especially important because the studied process is very common, the mechanisms that contribute to it are still studied and therefore new data is coming. Based on it, models of this process have been created and then analyzed in detail. Analysis of the models expressed as Petri nets have been based on t-invariants. They correspond to subprocesses occurring in the modeled system which do not change its state. Searching for similarities among t-invariants may lead to identification of subprocesses which interact with each other. This, in turn, may lead to discoveries of some previously unknown properties of the biological system. Such an analysis can be based on clustering of t-invariants. In addition, identification of MCT sets, i.e., sets containing transitions corresponding to exactly the same t-invariants, helps to identify important functional blocks of the system. In this work the application of this methodology to the analysis of processes related to atherosclerosis is presented and discussed.

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

#### 2 - Strong convex relaxations for the pooling problem

*Jonas Schweiger, Claudia D'Ambrosio, Jeff Linderoth, Jim Luedtke*

The pooling problem is a classic non-convex, nonlinear problem introduced by Haverly in 1978. In a nutshell, the task is to route flow through a network taking material qualities and bounds on these qualities into account. The point is that at each node of the network, the arriving material gets blended and therefore, the attribute qualities have to be tracked across the network which introduces bilinear terms into the model. We propose a novel convex relaxation that strengthens the state-of-the-art relaxation for the pooling problem. Being small enough for in-depth study, it still captures the essential structure of the problem. We provide a complete inner description in terms of the extreme points as well as an outer description in terms of inequalities defining its convex hull (which is not a polyhedron). We show that the resulting valid convex inequalities significantly strengthen the standard relaxation of the pooling problem.

#### 3 - The Most Reliable Flight Itinerary Problem

*Jan Fabian Ehmke, Michael Redmond, Ann Campbell*

Travel itineraries between many origin-destination (OD) pairs can require multiple legs, such as several trains, shared rides or flights, to arrive at the final destination. Travelers expect transparent reliability information to help improve decision-making for multi-leg itineraries. We focus on airline travel and making a priori decisions about flight itineraries based on the reliability of arriving at the destination within the travel time budget. We model the reliability of multi-leg itineraries and, given publicly available data, create probability distributions of flight arrival and departure times. We use these values in our reliability calculations for the entire itinerary. We implement a stochastic network search algorithm that finds the most reliable flight itinerary (MRFI). We also implement several ideas to improve the efficiency of this network search. Computational experiments help identify characteristics of the MRFI for a diverse set of OD pairs.

## ■ WB-07

Wednesday, 11:00-12:30 - WGS|106

### New Approaches for Combinatorial Optimization Problems in Manufacturing (i)

Stream: Discrete and Integer Optimization

Parallel session

Chair: Philipp Hungerländer

Chair: Anja Fischer

#### 1 - New Exact Approaches and Heuristics for Row Facility Layout Problems

*Kerstin Maier, Philipp Hungerländer*

Facility layout is a well-known operations research problem that arises in various applications. In this presentation we consider the following NP-hard row layout problem that has been recently suggested by [P. Hungerländer: The Checkpoint Ordering Problem. Optimization, to appear, 2017.]: The Checkpoint Ordering Problem (COP) asks for an optimal arrangement of one-dimensional departments with given lengths and weights such that the total weighted sum of their distances to a given checkpoint is minimized.

Furthermore we consider the well-known Multi-Row Facility Layout Problem (MRFLP), where the task is to determine the optimal placement of one-dimensional departments with given lengths and weights for each pair of departments on a given number of rows. The MRFLP is a very challenging optimization problem as the currently largest multi-row instances solved to optimality have only 16 departments.

We extend both the dynamic programming algorithm and the integer linear programming approach for the COP such that they now can handle an arbitrary but fixed number of checkpoints. We also suggest a heuristic for the COP that is based on our dynamic program. Additionally we propose how to use these methods in order to get high-quality bounds for the MRFLP. Finally we demonstrate the efficiency of our exact methods and heuristics for both the COP and the MRFLP on a variety of benchmark instances from the layout literature.

#### 2 - Extensions of the Double Row Facility Layout Problem

*Mirko Dahlbeck, Anja Fischer, Thomas Krüger, Uwe Bracht*

In this talk we consider the NP-hard Double Row Facility Layout Problem (DRFLP). Given a set of departments with positive lengths and pairwise (symmetric) transport weights between them, the DRFLP asks for an assignment of the departments to two rows and for horizontal positions of the departments such that the departments do not overlap. The aim is to minimize the weighted sum of the distances between the departments where usually only the center-to-center distances are regarded. We extend the model and the solution approach presented in Fischer et al. (2015) in various directions. Our new model is capable of asymmetric transport weights as well as individual in- and output positions of the departments. Clearance conditions between the departments can be taken into account. Moreover, given not only the lengths but also the widths of the departments, the used area for placing the departments can be restricted or optimized. In real-world instances there are often several departments of the same type. We show how to exploit this in the solution process. In the currently best DRFLP approach one iterates over all possible row assignments. We can significantly reduce the number of row assignments that have to be checked in the case of identical departments. Furthermore we illustrate additional constraints to break the symmetry of departments of the same type. So we are able to solve realistic instances with up to 21 departments in reasonable time. Without respecting the types of the departments the largest instances solved to optimality in reasonable time contained only 16 departments.

#### 3 - Optimisation-driven Heuristics

*Christina Burt*

In this talk, we will present a framework for creating quick-and-dirty heuristics while maintaining the hallmarks of an optimisation problem. That is, we should be able to guarantee we can find a feasible solution if one exists; and, what we "know" about the optimal solution should inform the search direction. The resulting framework is an informed decomposition that can be thought of as an approximate Benders scheme.

## ■ WB-08

Wednesday, 11:00-12:30 - WGS|107

### Railway Timetabling

Stream: Traffic, Mobility and Passenger Transportation  
*Parallel session*

Chair: *Christian Liebchen*

#### 1 - Structure-based Decomposition for Pattern-Detection for Railway Timetables

*Stanley Schade, Thomas Schlechte, Jakob Witzig*

We consider the pattern detection problem from the context of timetable analysis and rotation planning. Given a large-scale timetable that contains all trips of long-distance railway vehicles for one year, we want to identify weekly patterns in the timetable that are invariant. These patterns are interrupted by singular events like public holidays, which usually cause adaptations in the timetable, and interim changes for construction periods that require the redirection of vehicles. In a previous work we presented a Mixed Integer Linear Programming (MILP) approach to tackle and solve this pattern detection problem. In this paper, we look more closely at the problem specific properties and develop structure-based techniques. We propose a dual reduction technique which allows for the decomposition of the problem. In practice, the resulting subproblems are very small such that there is no need for using a MILP solver anymore. Furthermore, we analyse different heuristic approaches. Computational results for real world instances demonstrate that our methods are able to produce optimal solutions as fast as standard MILP solvers.

#### 2 - Timetable Sparsification by Rolling Stock Rotation Optimization

*Boris Grimm, Markus Reuther, Stanley Schade, Thomas Schlechte*

Planning rolling stock movements in industrial railway applications is a long-term process that gains accuracy the closer the day of operation comes. This process is regularly affected by man-made impediments like strikes. Even then, some employees may still be available, e.g., since they are not organized in a union. Consequently, a strike of a single union is more a heavy decrease of capacity than a complete lock down of the railway system. In such events the timetable, rolling stock rotations, maintenance plans, and crew schedules have to be adapted. Optimization methods are particularly valuable in such situations in order to maintain a best possible level of service using the resources that are still available. Finding new or revised cyclic tours of rolling stock vehicles (rotations) through the timetable after disruptions is a well studied topic in the literature, see Cacchiani et al. (2014) for an overview. Usually, a rescheduling based on a timetable update is done, followed by the construction of new rotations that reward the recovery of parts of the obsolete rotations. We consider a different, novel, and more integrated approach which, to the best of our knowledge, has not been described in the literature before. The idea is to guide the cancellation of the trips of the timetable by the rotation planning process, which is based on mixed integer programming. The goal is to minimize the operating costs while cancelling a trip inflicts opportunity costs, which are based on an estimation of the trip priority. The performance of the algorithm is presented as a case study of the German ICE train network of DB Fernverkehr AG for the strike period in May 2015.

#### 3 - On the Benefit of Preprocessing And Heuristics for Periodic Timetabling

*Christian Liebchen*

We consider the computation of periodic timetables, which is a key task in the service design process of public transportation companies. We are aware of only one collection of instances, the so-called PES-Plib. In the present paper, we aim at providing good solutions for the smallest and the largest of its instances (R1L1 and R4L4). We run a standard MIP solver (CPLEX) on a very elementary problem formulation. To come up with MIP sizes that fit better for standard MIP solvers, we propose to simplify the instances first, by invoking some basic preprocessing, parts of which having a heuristic character. Doing so, we improve the previously best-known objective value for R1L1 from 37,338,904 down to 33,711,523, and for R4L4 from 47,283,768 down to 43,234,156, i.e. by 9.7% and 8.6%, respectively.

## ■ WB-09

Wednesday, 11:00-12:30 - WGS|108

### Recent Developments in Column Generation (i)

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *Matthias Walter*

#### 1 - Modular Detection of Model Structure in Integer Programming

*Michael Bastubbe, Marco Lübbecke*

Dantzig-Wolfe reformulation applied to specially structured mixed integer programming models is well-known to provide strong dual bounds, though one of many requirements for implementing this method is structural problem knowledge. This is typically a reordering of the coefficient matrix to singly bordered block diagonal form. While searching such forms we pursue two goals: (a) try to retrieve what the modeler had in mind when building the model, and (b) find a vast variety of promising decompositions to facilitate studies on decomposition quality measures. In this talk we present a new modular, iterative algorithm to detect model structures in general mixed integer programming models aiming for these goals. After a pre-detection step, where constraints and variables are classified in various ways, we iteratively build a tree of successively more completed (refined) decompositions where each leaf is a complete decomposition. We demonstrate manifold refinement procedures, based on the pre-detected classifications, isomorphism detection algorithms, (hyper-)graph partitioning algorithms, and user given meta data. Finally we present computational results of our implementation integrated in the generic branch-and-price solver GCG.

#### 2 - Learning when to use a decomposition

*Markus Kruber, Marco Lübbecke, Axel Parmentier*

Applying a Dantzig-Wolfe decomposition to a mixed-integer program (MIP) aims at exploiting an embedded model structure and can lead to significantly stronger reformulations of the MIP. Recently, automating the process and embedding it in standard MIP solvers have been proposed, with the detection of a decomposable model structure as key element. If the detected structure reflects the (usually unknown) actual structure of the MIP well, the solver may be much faster on the reformulated model than on the original. Otherwise, the solver may completely fail. We propose a supervised learning approach to decide whether or not a reformulation should be applied, and which decomposition to choose when several are possible. Preliminary experiments with a MIP solver equipped with this knowledge show a significant performance improvement on structured instances, with little deterioration on others.

#### 3 - Refining column generation subproblems using Benders' cuts

*Jonas Witt, Marco Lübbecke, Stephen Maher*

When solving the linear programming (LP) relaxation of a mixed-integer program (MIP) with column generation, columns might be generated although the MIP admits an integer optimal solution that can be expressed without these columns. Such columns are called redundant and the dual bound obtained by solving the LP relaxation is potentially stronger if (some) redundant columns are not generated. To avoid generating redundant columns, we introduce a sufficient condition, which can be checked by solving a compact LP. If the sufficient condition is fulfilled, we can use a dual solution of this compact LP to generate classical Benders' cuts that eliminate redundant columns from the column generation subproblem. We implemented this refinement of the column generation subproblem in the branch-price-and-cut solver GCG and present computational results on structured as well as unstructured MIPs from the literature. Furthermore, we analyze the effect of this approach and discuss promising applications.

## ■ WB-10

Wednesday, 11:00-12:30 - WGS|108a

### Integer Linear Programming (i)

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *Gennadiy Averkov*

#### 1 - Integrality Gaps of Integer Knapsack Problems: Bounds and Expected Value

*Iskander Aliev*

We obtain optimal lower and upper bounds for the (additive) integrality gaps of integer knapsack problems. In a randomised setting, we show that the integrality gap of a “typical” knapsack problem is drastically smaller than the integrality gap that occurs in a worst case scenario.

#### 2 - Discrete quantitative Helly numbers

*Stefan Weltge, Gennadiy Averkov, Bernardo González Merino, Matthias Schymura*

Given a subset  $S$  of  $\mathbb{R}^n$  and a nonnegative integer  $k$ , what is the largest number of convex sets that have exactly  $k$  points of  $S$  in common, but every proper subfamily of these sets has more than  $k$  points of  $S$  in common? For  $k = 0$ , this refers to the classical Helly number of  $S$ . In this work, we study its quantitative generalization (for general  $k$ ) and provide a geometric interpretation of this number. This allows us to strengthen bounds recently obtained by Aliev et al. (2014) and Chestnut et al. (2015) for the case of  $S$  being the integer lattice.

#### 3 - Approximation of corner polyhedra with families of intersection cuts

*Joseph Paat*

The corner polyhedron provides a framework for deriving cuts for general mixed-integer linear programs. An inequality description of the corner polyhedron can be obtained by using the family of intersection cuts, which are derived from lattice-free sets. However, classifying lattice-free sets is a difficult endeavor, and therefore it seems intractable to access the entire family of intersection cuts. In light of this difficulty, we develop conditions for a family of intersection cuts to closely approximate the corner polyhedron. We examine the geometry of the lattice-free sets that generate these cuts, and in doing so, we characterize “strong” approximations based upon the number of facets of the lattice-free sets. This work was done in collaboration with Gennadiy Averkov from the University of Magdeburg in Germany and Amitabh Basu from Johns Hopkins University in the USA.

## ■ WB-11

Wednesday, 11:00-12:30 - WGS|005

### Liner Shipping Optimization I

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: *Kevin Tierney*

#### 1 - The Flexible Ship Loading Problem

*Dario Pacino*

Liner shipping companies have adapted to the growth in the transport volumes by increasing the capacity of their services. This is done by deploying larger vessels of over 19,000 TEU and planning more frequent visits to the container terminals. Capacity is, however, not enough. A reliable shipping service requires the goods to arrive on time, so container terminals should supply reliable and fast operations for their customers. The increase in vessel’s size intensifies the pressure on the container terminals. Meanwhile, slow-steaming has increased the time spent in the open sea. An outcome of slow-steaming is that liner shipping companies deploy many more vessels to the services and this increases the peak of workloads on the container terminals. It is for these reasons that the collaboration between container terminals and ship owners is growing more and more important. In this talk, we introduce the Flexible Ship Loading Problem, which is the planning of loading operations for a container vessel. By allowing

container terminals to adjust stowage plans, we gain enough flexibility to improve resource utilization and reduce the vessel’s turnaround time. During the talk, we will introduce a novel mathematical formulation that can solve small size instances. For larger instances, we propose a matheuristic.

#### 2 - Stowage planning: A benchmark and a novel heuristic

*Rune Larsen, Dario Pacino*

With the ever-growing size of container vessels and the fact that the liner shipping industry is surviving off marginal revenue, using advanced planning methods has never been more relevant. One of the main revenue drivers in liner shipping is vessel utilization. A number of scientific articles tackle this problem on a strategic or tactical level by optimizing fleet size and composition or optimizing the design of the shipping network. On an operational level, the capacity of a vessel and its efficiency at port is dictated by the so-called stowage plan. A stowage plan describes the arrangement of the containers on the vessel. Stowage plans are not easy to produce. This is not only due to the large number of containers that needs to be planned, but also due to a complex set of physical restrictions that govern the balance and stability of a vessel. Research on stowage planning has been plagued by missing data and by not having a common problem definition. In this talk we will introduce the first publicly available benchmark on stowage planning. The data collected for the benchmark is based on a real vessel, where simplifications have been made to make the problem more accessible to an academic audience. A novel large neighborhood search has been implemented to solve the stowage planning problem. Details about the algorithm and preliminary results on the new set of benchmark instances will be showcased during the talk.

#### 3 - The Stochastic Liner Shipping Fleet Repositioning Problem with Uncertain Container Demands

*Stefan Kuhlemann, Kevin Tierney*

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 the changing demands of customers. A deterministic model for the Liner Shipping Fleet Repositioning Problem (LSFRP) exists, but many input parameters to the LSFRP are uncertain. Assuming these parameters are deterministic could lead to extra costs when plans computed from 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 introduce an optimization model for the stochastic LSFRP, focusing first on the uncertainty involving container demands. This model is evaluated with several scenarios originating in the industry. We then discuss business insights related to considering uncertainty during planning.

## ■ WB-12

Wednesday, 11:00-12:30 - WGS|BIB

### Business Track I

Stream: Business Track  
*Parallel session*

Chair: *Michael Beck*

#### 1 - Introduction of optimization systems in public transport companies

*Michael Beck*

In this lecture the problems of the introduction of optimization systems for vehicle and driver scheduling will be presented. In the meantime, universally configurable systems are available for solving problems in transport companies, but the introduction of such systems is difficult and time-intensive. In the case of the manual or semi-automatic methods used so far the quality of the solutions are based on the expert knowledge of the users, which is insufficiently documented and can be incorporated into the configuration of the optimization procedures only in iterative working steps. This method often leads to dissatisfaction of the customers, because of initial bad results and long implementation times. Furthermore, the aspects of data quality and the comparability of solutions are presented. This is particularly relevant for driver duty optimization, because not only financial costs are taken into account by the optimization, but also aspects which can’t be quantified easily, e.g. social acceptability.

## 2 - Impact of efficient algorithm implementation on the performance of heuristic optimization

*Michael Feichtenschlager*

The inola Advanced Optimization Core is a reliable, self-learning, heuristic optimization technology which is particularly useful for solving practical complex constrained operations research problems. Generic heuristic optimization methods have the disadvantage of not being able to provide evidence for global optimal solutions, so the computed solution should be delivered fast and of high quality. In the presentation, the importance of efficient algorithm implementation will be demonstrated by means of practical routing tasks, which has been implemented with the inola AOC. Using different algorithm designs, the impact on performance will be analyzed by pre-post comparison. Small changes in just parts of selected algorithms can lead to a significant improvement in the application's performance. In addition to the importance of efficient algorithm implementation another aspect, why heuristic optimization methods can fail, is the lack of a proper solution space exploration. The optimization method shall only cut-off areas of the solution space, in which the optimum will never be found, which is by default a challenge of optimization.

## 3 - Research in operations - the aircraft maintenance, repair and overhaul market

*Michael Frank*

For maintenance, repair and overhaul (MRO) of aircrafts, used parts from other airplanes are used. The sell, loan and exchange of used aircraft parts is a big market. MRO providers offer flat rate deals to airlines that cover all expenses of MRO operations. These deals require a lot of operations research: Demand for spare parts need to be forecasted, values for spare parts in various conditions must be determined and most efficient economical use of existing stock calculated. The presenter will give a brief insight in a solution for a big MRO provider. Applied methods include forecasts based on stochastic processes for demand prediction. Additionally a combination of various regression models are used for value determination. Optimization models support buy/sell decisions and the most efficient use of stock parts. The models itself are of interest not only due to their complexity but also due to the enhancements to handle all kind of missing data cases. The solution for this MRO provider is tailor made. The presentation will show examples for other custom-made OR solutions. That should support the thesis that successful OR implementations are mostly tailor made.

## ■ WB-13

*Wednesday, 11:00-12:30 - RVH|I*

### Forecasting Neural Network Specification

Stream: Business Analytics, Artificial Intelligence and Forecasting

*Parallel session*

Chair: *Sven F. Crone*

### 1 - Visually Supported Parameter Tuning and Feature Engineering for Artificial Neural Networks

*Dennis Eilers, Cornelius Köpp, Michael H. Breitner*

A successful application of artificial neural networks in practical business analytics applications mainly depends on how well the available data represent the problem statement and the model capabilities to learn the dependencies in the presented patterns. Engineering the right features (independent variables) and tuning the model parameters is therefore a major challenge and requires technical expertise as well as domain knowledge about the investigated problem. In this study, we show how heat map visualizations of model errors can be used to assess the suitability of selected network properties and features. The proposed heat map approach visualizes the performance of the models in a two-dimensional feature space which allows a local representation of the accuracy to identify misspecifications or necessary adjustments. Experiments with different network topologies and feature representations show how location dependent error visualizations can provide a more comprehensive quality criterion than a single performance measure like the root-mean-square error. The gained insights help to find adequate parameters like the number of hidden layers/neurons in a feed-forward neural network. Moreover, additional features can be constructed and evaluated based on their influence on the error distribution. We also discuss practical as well as theoretical implications based on the observed phenomena.

## 2 - Learning uncertainty of predictions by neural networks with regression

*Pavel Gurevich, Hannes Stuke*

In the talk, we discuss a general flexible approach to uncertainty quantification for predictions performed by deep neural networks. It is based on the simultaneous training of two neural networks with a joint loss function. One of the networks performs regression and the other quantifies the uncertainty of predictions of the first one. Unlike in many standard uncertainty quantification methods, the targets are not assumed to be sampled from an a priori given probability distribution. We analyze how the hyperparameters affect the learning process and show that our method allows for better predictions compared to standard neural networks without the uncertainty counterpart. Finally, we establish a connection between our approach and the mean variance estimation method and the mixture density networks.

## ■ WB-14

*Wednesday, 11:00-12:30 - RVH|II*

### Class and Score Prediction

Stream: Business Analytics, Artificial Intelligence and Forecasting

*Parallel session*

Chair: *Thomas Setzer*

### 1 - Consumer's sport preference as a predictor for his/her response to brand personality

*Friederike Paetz, Regina Semmler-Ludwig*

Within a purchase decision process consumer often tend to choose that branded product, which arouses the most positive brand affect, rather than taking certain product attributes into account. Brand personality - human characteristics associated to a brand - is known as a central driver for affective brand loyalty. Recent studies already revealed, that consumers prefer those brands, which are in line with their own personality traits. Because brand personality is created by organization's communication mix, organizations may therefore explore the personality traits of their target market segments and attach the corresponding personality to their brand. However, focusing on consumers' personality traits for market segmentation is challenging, since personality traits are not directly observable. Hence, linking personality traits to variables, which are easily observable, may reduce organization's communication effort. Within our study, we explore the personality traits of sportsmen from several sport clusters, e.g., sport players, sport fighters etc. To measure sportsmen's personality, we used the popular Big Five approach, which describes personality by five factors, i.e., extraversion, neuroticism, agreeableness, conscientiousness and openness. We found evidence that the considered sport clusters significantly differ within certain personality traits. E.g., nature sportsmen turned out to be most extravert and open, while fitness sportsmen are most conscientious. Hence, consumer's choice of a specific kind of sport may be used as a predictor for his/her response to brand personality, i.e., affective brand loyalty. Sport organizations may use these results to simplify their communication strategies.

### 2 - Credit Scoring based on Neural Networks

*Ralph Grothmann, Hans Georg Zimmermann*

For financial institutions, credit risk assessment is key to their business success and as it is also vital for the economy as a whole, the prediction models attract high attention from regulators. Despite substantial developments in the area of machine learning recently, most banks still rely on traditional methods like logistic regression. Since data is expensive to obtain, most publications which applied machine learning techniques to credit scoring have used datasets with less than 1,000 observations. Another common shortcoming is that problems with heavily imbalanced data are often bypassed by using an artificially high default rate of around 50 percent whereas the share in banks' credit portfolios usually is around 1 to 3 percent. We used a real-world dataset of 183,000 observations with 1.39 percent defaults and applied seven different machine learning techniques including ensemble learners. Our results give clear indication that especially state of the art techniques like boosting algorithms outperform traditional risk models significantly.

### 3 - Customer Churn Prediction using Temporal Patterns in Support Contact Data

*Katerina Shapoval*

The telecommunications industry is characterized by a strong price competition and high annual churn rates of about 30 %. Furthermore, the acquisition costs per customer are about seven times higher than the retention costs. These circumstances make accurate churn prediction a crucial task for a telecommunications company in order to sustain in the market. Usually, the data available to the company includes records about the support history of a customer. To date, multiple approaches to predict churn exist, however, support data and its impact on churn prediction quality did not get a wide attention among scientific publications. This work aims at analysis and extraction of temporal patterns from support contact history of a customer (e.g. channel with the corresponding number of contacts and high-level description of its reason) as well as subsequent integration of these into churn prediction models. In particular, the predictive value per contact channel and the respective attributes with respect to the predictive power of a following churn event is investigated. A further challenge is the reduction of temporal patterns with respect to the history length and event variety in a multi-channel setting to a concise attribute set. For this purpose, a temporal discounting is employed, which weights the information with the assumption that the latest event has the highest importance. Overall, the empirical study based on the data of a telecommunications company shows a significant influence of the extracted attributes and patterns. Thereby, the recommended methodology of pattern extraction has shown beneficial results, both in descriptive and predictive purposes, so that the relevant patterns can be interpreted and employed in predictive models for churn.

## ■ WB-15

*Wednesday, 11:00-12:30 - RVH|III*

### Modelling and Simulation in the Service Industry

Stream: Simulation and Statistical Modelling  
*Parallel session*

Chair: *Lars Ostmeier*

#### 1 - A case study of simulating the surgical process flow in an Indian healthcare setting

*Rakesh Verma, Sudhanshu Singh*

The use of simulation has increase over the years , moreover so after the tremendous gains in computing power since the 1980s. Organizations use simulation modelling to assess , evaluate the alternatives and for testing new solutions which may not too complex for analytical modelling. Simulation software has developed its capability in parallel with the growth in computing power since the 1980s. Simulation lets us visualize situations which have not really happened but what could happen. We present a simulation study to bring enhanced understanding of the surgical process in an Indian hospital . The results indicate the need to have tighter control on activities that are related to patient readiness for better throughput of the surgical process. This approach brings in more clarity and makes decision makers more realistic on what could be done.

#### 2 - Toward an Agent-based Simulation of Incentives and Disincentives for Sharing Frailty-Related Information in Perioperative Care

*Daniel Furstenuau, Felix Balzer, Martin Gersch, Claudia Spies*

Elderly patients undergoing surgical interventions are prone to develop frailty-related complications that may go far beyond the index hospitalization. Yet, biological aging-relevant information are currently not fully integrated into hospitals' perioperative processes. This study combines research on frailty and economics of standardization in a novel way by asking: What is the best design regarding patient data compilation that aligns incentives of involved actors in order to reduce frailty-related complications?

A simulation is specified. It compares four scenarios for integrating frailty-related data into perioperative processes. First, general practitioners, second, decentralized ambulatory clinics within the hospital,

third, the hospital's emergency room, and forth (baseline), the anesthesia unit compiles the data. Our simulation uses the case of perioperative care provided by Charité's department of anesthesiology. Actor-related incentive data was collected from 13 interviews, observations, and further documents.

Qualitative analysis suggests that (1) there is general willingness by all parties to participate in data sharing, (2) the earlier the compilation the better, (3) unbalanced cost/utility structures hinder implementation. Calibration with actual cost and outcome data is ongoing.

By focusing on frailty-related data exchanges and using agent-based simulation, the study directly addresses biological aging-related processes. Increasing problem awareness is shown by the fact that Charité has implemented a special track for elderly patients scheduled for elective surgery. This solution could perhaps be extended.

Simulation promises to explicate better decision processes in health-care and test designs to improve health-related outcomes.

### 3 - Evaluating intra-day quantity risk of wind power production

*Lars Ostmeier, Sven Kolkmann, Christoph Weber*

We aim at developing a multivariate model of wind power forecast errors reflecting the economic characteristics of the short-term markets as well as the physical characteristics of wind power forecasts and updates. First theoretical hypotheses are formulated for later empirical validation. Then a multivariate specification is proposed reflecting forecast errors as a function of delivery period and time to maturity. Hypothesis 1 starts from the assumption that the forecasts fully reflect the information available at the forecasting time  $t$ . Then later updates of forecasts are a consequence of new information. We hypothesize that this new information leads to random changes in forecasts (no autocorrelation between subsequent forecast updates). Hypothesis 2 is reflecting the assumption that changed observations in the underlying physical system will affect monotonously forecasts for different time horizons. In line with numerous studies on probabilistic wind power forecasting, we first specify univariate distributions for forecast updates for single forecast horizons and then we apply copula to describe multivariate processes. Having calculated the forecast errors as defined above, we choose a non-parametric approach to estimate the cumulated distribution function (CDF) of the forecast updates for different time horizons. Therefore, we avoid limitations due to the predefined form of a specific distribution function. Following literature on wind power forecasts, we consider inter alia Support Vector Machines, kernel density estimation and quantile regression. Next, a multivariate Gauss-Copula is fitted to the cumulated distribution functions. The fitted multivariate distribution may then be used for Monte-Carlo simulations of future infeed scenarios.

## ■ WB-16

*Wednesday, 11:00-12:30 - RBM|1102*

### Finance I

Stream: Finance  
*Parallel session*

Chair: *Michael H. Breitner*

#### 1 - Decoupled Net Present Value - An Alternative to the Long-Term Asset Value in the Evaluation of Ship Investments?

*Philipp Schrader, Jan-Hendrik Piel, Michael H. Breitner*

The aftermath of the financial crisis has threatened the stability of several financial institutions over the past years. Most heavily hit were banks with a notable exposure to ship finance, who saw the collateral value of many loans being diminished. Industry observers trace back the rare occurrence of actual defaults of ship loans to the use of the Long-Term-Asset Value (LTAV), a valuation method explicitly designed for ship investments. As the LTAV is based on a discounted cash-flow approach, it accounts for investment risks in the discount rate. Consequently, the LTAV bundles the time value of money and risk in a single value, which begs the question if this method oversimplifies the incorporation of risk in the evaluation of ship investments. In the context of infrastructure investments, the Decoupled Net Present Value (DNPV) has recently been proposed as an alternative method that addresses the problem of using risk-adjusted discount rates. It separates



the time value of money from risks by quantifying risk factors individually and treating them as costs to the investment. We provide a proof-of-concept regarding the applicability of the DNPV in the context of ship investments. To this end, we develop a DNPV valuation model and instantiate a prototype in Python. We then perform a simulation study that evaluates a ship investment using both the LTAV and the DNPV. The results of our study confirm the applicability of the DNPV to ship investments and point to both its advantages and limitations compared to the LTAV.

## 2 - The Innovator's Dilemma revisited: Investment Timing, Capacity Choice, and Product Life Cycle under Uncertainty

*Stefan Kupfer, Elmar Lukas*

Innovative industries like the semiconductor or flat-panel industry have been a driving momentum of global growth for decades. However, global competition, constant decline of output prices, rocketing costs, and shorter life-cycles put great stress on making the right investment policy. By means of a Markov-regime switching model we model the simultaneous choice of optimal investment timing and capacity under uncertainty in continuous time. Our results indicate that, the threat of disruptive technological change lead to install less capacity later. If uncertainty levels in each demand regime are different, we find that both optimal capacity and timing threshold become ambiguous. For low degrees of uncertainty in the decline regime, an increase of uncertainty leads to an increase of the investment threshold and a decrease of the optimal capacity in the growth regime.

## ■ WB-17

Wednesday, 11:00-12:30 - RBM|2204

### Data-driven Healthcare Services

Stream: Health Care Management  
Parallel session

Chair: *Melanie Reuter-Oppermann*

#### 1 - Data-based Location, Relocation and Dispatching Approaches for the German EMS System

*Melanie Reuter-Oppermann*

In the last couple of years more and more papers have been published that present approaches for determining ambulance relocations and that show the benefit of applying those approaches, for example in the Netherlands. Nevertheless, ambulance locations in Germany are still mostly static. Ambulances are usually waiting for a call at their home base and they are sent back there after an emergency rescue. In addition, always the closest ambulance is assigned to an emergency independent of the severity and the current status of the system, even though researchers have shown that this is not always optimal for the overall system. The question arises if ambulance relocations and different dispatching rules can be applied in German practice in order to improve the performance, i.e. reduce response times. Therefore, promising approaches proposed for the Dutch EMS system were adapted to the German system and tested for several instances. The most important adaptations model the facts that emergency doctors are often called to the scene in addition to an ambulance and that in case of several patients also multiple ambulances might be necessary. The test instances were generated for different EMS regions in Germany based on the results of a data analysis to study the impact of the underlying network structure on the performance of the approaches. In addition, the locations of the home bases for the ambulances were varied based on the results of different ambulance location models.

#### 2 - Semantic Data Verification by Means of Human-Readable N3 Rules

*Tobias Weller, Maria Mareshkova*

Bad data cost the U.S. businesses \$611 billion in 2013 and \$314 billion to the U.S. healthcare. At the same time the digitalization of healthcare information continuously grows. The volume of electronic health records is estimated to increase worldwide from 500 petabytes in 2012 to 25,000 petabytes in 2020. Due to the growing data volumes, costs, affected by bad data, raise as well. Reasons for bad data are, for example, miskeying, miscommunication, wrong entry and fraud entry of data. Data Verification is a process, in which data is checked for inconsistencies and accuracy. The goal of Data Verification is to detect

invalid and faulty data. Usually, the data is checked after Data Migration and not while entering new data. We propose a novel approach for extending the usual usage scenario of Data Verification by introducing N3 for checking for invalid data stored in a system. While N3 rules are typically used to infer new knowledge, based on the information stored in a knowledge base, we formalize verification checks in N3 rules and apply them on the saved data. The outcome of the inferred information can be used to check if the entered data is consistent. As a use-case scenario, we formalize conformity checks from a hospital information system in N3. The formalized N3 rules can also be used to automatically suggest entry values. We define multiple test scenarios to evaluate the expressivity and applicability of our approach. We also show that our approach is not limited to a certain use-case scenario but can be applied to further domains beyond healthcare.

#### 3 - Appointment planning data - between desire and reality

*Anne Zander, Melanie Reuter-Oppermann, Stefan Nickel*

The literature offers many models to improve the appointment planning of a medical practice. Unfortunately, the implementation of these models often fails due to the unavailability of certain data. One reason for this is that medical practices often use software that is designed to comply with the billing regulations but not to collect data in order to plan better. In this talk, we will first summarize the most important data that is needed to implement the appointment models from the literature. The models we cover range from intra-day appointment planning with a focus on direct waiting times to inter-day appointment planning with a focus on indirect waiting times (access times). In the second part of the presentation, we investigate the appointment data we obtained from several medical practices. We then discuss what models (with their corresponding objectives) can be applied using this data. Subsequently, we will discuss what kind of data is not available. We show how the medical practices could benefit from collecting this data through applying the corresponding models.

## ■ WB-18

Wednesday, 11:00-12:30 - RBM|2215

### Scheduling and Sequencing

Stream: Project Management and Scheduling  
Parallel session

Chair: *Stefan Bock*

#### 1 - Tabu search algorithms for scheduling tasks with ready times on a single machine with limited availability

*Jakub Pietruczuk, Piotr Formanowicz*

In classical scheduling theory it is usually assumed that machines are continuously available for processing tasks. However, in many real life situations this assumption is not fulfilled. There are many reasons making machines not available in some periods of time, e.g., the limited availability may result from maintenance activities, from overlapping of time horizons in rolling time horizon planning algorithms or it may be due to scheduling of tasks with various priorities. In general, in deterministic scheduling two cases are considered, i.e., the starting points of the non-availability periods are known in advance or they should be determined to meet some requirements (when they correspond to maintenance - in this case both, tasks and maintenance have to be scheduled). In this work problems of scheduling tasks with ready times on a single machine with many non-availability periods are considered. The starting times and lengths of these periods are a part of the problem instance and the optimality criteria are minimization of the makespan and minimization of the sum of completion times. Since the problems are computationally intractable, tabu search algorithms solving them are proposed. The quality of the algorithms has been verified in extensive computational experiments whose results are reported.

#### 2 - A branch and bound procedure for a scheduling problem with fixed delivery departure dates

*David Bachtenkirch, Stefan Bock*

In many classical scheduling problems completed jobs are assumed to be delivered to another production stage or delivered to a customer at the point of completion. Scheduling problems with fixed delivery departure dates model cases where completed jobs must be held in inventory until delivery is available at certain points in time. Such circumstances are often found in the industry when a manufacturer relies on third party logistics providers to ship products to customers.

In this talk we present an optimization problem which focuses on minimizing holding and transportation costs for a set of jobs from multiple customers where jobs can only be delivered at certain fixed delivery departure dates. A job needs to complete production and must be assigned to a departure date before its deadline is exceeded. Completed jobs are held in inventory until transportation starts. Jobs can be delivered in batches at customer specific delivery departure dates by means of a direct delivery method.

Properties of the problem are investigated and used to construct an exact branch and bound solution procedure. We propose an enumeration scheme which partitions jobs into production blocks, derive an efficient subproblem evaluation method and present dominance criteria making use of the underlying problem structure. Additionally lower and upper bounds are presented. We give a brief overview of the computational results, comparing the branch and bound procedure and a standard MILP solver.

### 3 - A pseudo-polynomial solution approach for optimally solving the acyclic TSP with multiple congestion scenarios and soft due date restrictions

*Stefan Bock*

In this talk, an acyclic TSP with multiple congestion scenarios and soft due date restrictions is considered. In order to adequately map unreliable transportation data, multiple congestion scenarios are integrated. Each scenario may be derived from past data and determines congestion-dependent travel times. The problem pursues a hierarchical objective function. As the primary target, the total weighted tardiness for all defined congestion scenarios is minimized. The secondary objective is the minimization of the weighted makespan. The resulting problem is strongly NP-hard if either the number of congestion scenarios or the number of routes are allowed to increase linearly with the number of requests. Moreover, this is also true if non-zero unloading times at the delivery locations are integrated. However, if all three aforementioned cases do not apply, the problem is binary NP-hard, but can be solved to optimality in pseudo-polynomial time. By integrating an efficient dominance rule and tight lower bounds, a best-first Branch&Bound algorithm is proposed. Its high practicability is evaluated for various scenarios by a computational study.

## ■ WB-19

Wednesday, 11:00-12:30 - RBM|3302

### Production and Service Networks

Stream: Production and Operations Management  
*Parallel session*

Chair: *Tristan Becker*

#### 1 - Comprehensive MRP-concept for complex products in global production and supplying networks

*Wilmjakob Herlyn*

Nowadays product complexity is increasing and networks are expanding e.g. an automotive OEM operates up to hundred plants and have thousands of suppliers. Under these actual conditions we need an appropriate MRP-concept to master this. Often material flow is mapped by graphs, but this method reaches its limitation for complex products and expanded networks because of an enormous amount of nodes and edges. This is one reason why MRP is performed separately not only for different companies but also for different plants. The presented MRP concept bases on the mathematical fundament of an ideal Boolean Interval Algebra which is a 'particular class' of Boolean Algebras with a 'linear order'. We assume that the production and shipping built a sequence of consecutive intervals, which can represent any kind of production and material flow (PMF) section like manufacturing shops, shipping routes or warehouses, so it doesn't matter whether the products and their components are made inside or out-side a company. Each interval resp. PMF-section starts with an Entry-Point (EP) and ends at the EP of the next-following interval. As a result we've got a sequenced chain of EP's which built a consistent frame-work wherein material can flow only. The product structure, mapped as 'Bill of Material' (BOM), is linked to the concerned EP of the PMF-structure, so we can use this for a 'bundle' of similar products or component variants. By this way we can reduce the network complexity and we can use the same MRP-parameter like lead-time or working-calendars for each PMF-section. The described explicit PMF-schema is the fundamental database for different MRP-methods like backward calculation, planning by 'Control-loop-Cycles' and creating cumulative curves

#### 2 - Service Network Design: Competing on Convenient Locations and Responsive Service Processes

*Pratibha Saini, Cornelia Schoen, Fabian Stroh*

We present a market-oriented service network design model with an attraction model of customer choice as the underlying demand model. We assume demand as a function of waiting time and distance, among other attributes. The service provider's objective is to maximize profits, and the number of facilities, their locations, the design of the service process at each facility (in particular with regard to process capacity and service level) are the main decision variables. In the literature on stochastic location models with congestion, service facilities have typically been modeled as single stage queuing systems with single or multiple servers. We complement this work and model each facility as a multi-stage queuing network with multiple servers. This assumption fits well for many service facilities, e.g. food outlets (e.g. Vapiano, Starbucks etc.) and public facilities (e.g. bank, government offices etc.). We capture the uncertainties related to demand and service process at a facility through an ex ante simulation and derive performance measures related to the underlying queuing network with respect to possible demand and capacity configurations. The output is incorporated into the service network design model. Mathematically, the optimization model is nonlinear mixed-integer, and can be linearized using "big M" constraints and several auxiliary variables. Since practical applications may require to solve large-scale instances, we investigate heuristic solution procedures and present a case study of designing a new pizza delivery service in Germany.

#### 3 - Tactical Planning of Modular Production Networks With Reconfigurable Plants

*Tristan Becker, Stefan Lier, Brigitte Werners*

Process industries are confronted with increasingly difficult market circumstances in recent years. A large number of customers demand a high number of specialized products, which are characterized by shortened product life cycles. As a result, the exact type and location of demands are subject to a high degree of uncertainty. Recently, the use of modular plants has received much attention as an answer for these new challenges. Modular plants consist of standardized process modules, which allow for quick assembly, disassembly and relocation of production plants. Depending on the combination of process modules, different production capabilities are associated with a production plant. Further, production plants can be reconfigured by changing one or more process modules, to quickly alter the type of production capacity which is provided by a plant. In consequence, the flexibility of the production network is strongly increased. We analyze novel mixed integer programming formulations for production network planning with and without consideration of short-term plant reconfigurations and capacity shifts. In a case study with adjusted real-world data from the chemical industry, we investigate the value provided by the additional flexibility of plant reconfigurations.

## ■ WB-20

Wednesday, 11:00-12:30 - RBM|4403

### Closed Loop Supply Chains

Stream: Supply Chain Management  
*Parallel session*

Chair: *Patricia Rogetzer*

#### 1 - An Integrated Approach for Assessment of Green Suppliers with Interval Type-2 Fuzzy Sets

*Ahmet Çalık, Abdullah Yıldızbaşı, Turan Paksoy, Alexander Kumpf*

Environmental challenges, such as global warming, overpopulation, climate change, water pollution have forced many companies to consider Green Supply Chain Management (GSCM) to achieve competitive advantage in the globalized market. Selection of appropriate suppliers is a fundamental key which contributes the companies' performance directly. Even though supplier selection has received considerable attention from researchers, the studies usually include the traditional factors such as quality, price and late delivery. In order to enable the sustainable development of companies, environmental criteria including carbon-dioxide emission and waste reduction should be integrated into the traditional criteria. The main objective of this study is to evaluate suppliers' performance using an integrated approach which

has two stages with environmental issues. At the first stage, Fuzzy Analytic Hierarchy Process (FAHP) with interval type-2 fuzzy sets is used to handle experts' subjective judgments'. It is more meaningful to use interval type-2 fuzzy sets in MCDM problems because of easy of usage, lower computational time and effort. At the second stage, a fuzzy multi-objective linear programming model is developed to determine what the optimal order quantity is and which suppliers should be selected. In the application part, proposed integrated approach is applied to select the green suppliers and determine order quantity with respect to different experts' judgments. A numerical example is presented to demonstrate the effectiveness of the proposed approach.

## 2 - Coordination of grading in reverse supply chains

*Gerrit Schumacher, Moritz Fleischmann*

In reverse supply chains, the quality condition of used products is a critical issue. Therefore, grading and the subsequent disposition decision are essential. These two processing steps fundamentally distinguish forward and reverse supply chains. Yet acquisition and grading are commonly subcontracted, i.e. executed by a different firm than the one eventually reprocessing and reselling the used products. In this presentation, we address potential incentive conflicts arising from this supply chain setup. Specifically, we present a model for the depicted situation with the goal to overcome the incentive conflicts with a coordination mechanism.

## 3 - Sustainable sourcing with recycled materials: A contribution towards circular economy

*Patricia Rogetzer, Lena Silbermayr, Werner Jammerneegg*

Recycling rates for certain materials like aluminum are high, but often far below to fully meet an economy's total demand. As the demand for raw material experiences a steady increase, the use of recovered raw materials can help to pave the way towards a circular economy, i.e. the integration of recycled material into the sourcing strategy plays a crucial role. This could be beneficial not only in terms of the environment and the society, but is also economically relevant. We address such an issue faced by a manufacturer who finds its optimal strategy by sourcing from two suppliers: one delivering virgin material, the other offering recycled material with uncertain yield and price. The focus of this work is to discuss how the integration of recycled material impacts a manufacturer's economic performance. Depending on the price difference between virgin and recycled material, we want to explore, which sourcing strategy is most desirable from an economic point of view. This is analyzed for a short life-cycle product in a single-period inventory model framework. As the delivery quantity of the recycler does not necessarily equal the order quantity, the following sourcing strategies are considered: 1. single sourcing from the recycler, 2. single sourcing from the virgin material supplier, 3. dual sourcing from recycling and virgin material supplier, 4. dual sourcing with recycling material as a main source and an emergency option of virgin material. For every sourcing strategy the optimal order quantities are provided that maximize manufacturer's expected profit. Our preliminary results indicate that for a certain range of prices from the recycler the dual sourcing approaches will lead to higher profits compared to single sourcing.

complex structures. Arriving at this point additive manufacturing becomes important because it enables us to manufacture these extremely complex structures including undercuts or hollow spaces, provided by the optimization program.

For this reason we developed a linear optimization model to describe static load cases in relation to framework structures. By using a graph network it will be possible to reproduce the assembly space of a additive manufacturing system. The model describes any number of transmitted forces into the framework structure which are working against the forces being exerted by the assumed bearings. The model determines independently where and which capacities are needed at a particular position within the assembly space, whereas it can choose from a given quantity of connecting elements (e.g truss girders). The aim of the beam structure optimization for additive manufacturing is to reduce material and improve the field of lightweight construction, with the aim of saving costs overall.

## 2 - Modeling variants for the Multiple Traveling Salesmen Problem with Moving Targets

*Anke Stieber*

The multiple traveling salesmen problem with moving targets (MT-SPMT) is a generalization of the classical traveling salesmen problem, where the targets are moving over time on arbitrarily shaped trajectories. Additionally, for each target a visibility time window is given. The task is to find routes for several salesmen so that each target is reached exactly once within its visibility time window and the sum of all traveled distances of all salesmen is minimal. The targets and the salesmen are assigned a certain speed value. Then an arc between two targets for two certain times exists, if the distance between the positions at the respective times of both targets can be traversed by a salesman at its maximum speed value. Applications of the described problem class can be found, e.g., in supply logistics and in the defense sector. Such instances can be very large in the number of variables and therefore time consuming to solve numerically. In handling the time aspect in different ways we present distinct modeling approaches for the MTSPMT. Firstly we use discrete time steps and embed the problem in a time-expanded network. Secondly, we use additional continuous variables to present a time-continuous model. This variant yields more accurate objective function values. Finally a time-free approach is proposed. In this so-called master problem the time aspect is relaxed completely and then time feasibility is ensured by solving a number of subproblems, that incorporate the two former model variants. Computational results for randomly generated test instances to compare all different modeling approaches were carried out.

## 3 - Domain Specific Pre-Analysis and Generation of Optimization Problems

*Benjamin Saul, Wolf Zimmermann*

Mixed-integer linear programs can be used to solve different problems. However, many methods need understanding of complex mathematical models. Using a domain-specific language to formulate the specification makes these methods available to more users. In our work we implemented a language for optimal pumping systems, a graph based selection problem. The mixed-integer linear program is then generated from the domain-specific model. The model can be analyzed to emit user feedback wrt. feasibility and numerical stability. Analysis results can be used to reduce the solution space by removing variables and tightening bounds.

## ■ WB-21

Wednesday, 11:00-12:30 - RBM|4404

### Technologies of Artificial Creativity

Stream: OR in Engineering

Parallel session

Chair: Ulf Lorenz

#### 1 - Beam structure Optimization for Additive Manufacturing

*Christian Reintjes, Michael Hartisch, Ulf Lorenz*

The current progress in construction industry indicates that there is a huge interest to use generative design, or in general, optimization models, for developing products with highly complex geometries. It is the desire to use computational forces in form of optimization programs and to combine them with the design experience of engineers. Using both, it is possible to generate construction proposals beyond human abilities. The problem is that the conventional manufacturing techniques, like milling, turning or casting, are just not able to produce such

## ■ WB-22

Wednesday, 11:00-12:30 - HFB|A

### Energy and Mobility

Stream: Energy and Environment

Parallel session

Chair: Magnus Fröhling

#### 1 - Driven by change? EV drivers' acceptance and perceived productivity at Deutsche Post DHL

*Stefanie Wolff, Reinhard Madlener*

In times of escalating amounts of parcel shipments and tightening urban air quality legislations, the logistics sector introduces EV in city operations. Numerous studies deal with economic and environmental facets of electrifying commercial fleets. Yet, the question remains whether light duty EV (LDEV) add value to logistics operations, particularly to the drivers.

Deutsche Post DHL is gradually electrifying its vehicle fleet by substituting diesel cars by LDEV. In the area of Bonn, they operate around 170 LDEV, using various LDEV models with a few diesel cars being kept as reserves. Drivers have been using LDEV on a daily work basis for 3-4 years, which allows us to analyze long-term user acceptance.

By conducting a cross-sectional survey at Deutsche Post DHL, we examine to what extent drivers accept the substitution of diesel cars by LDEV. Specifically, we investigate drivers' LDEV acceptance from two perspectives. First, are the drivers more satisfied with the LDEV than with the diesel vehicle? Second, does the EV increase perceived productivity? Combining these two perspectives, our working hypothesis states that the greater the drivers' overall satisfaction with the LDEV, the higher their perceived productivity.

We modeled our hypothesis by means of latent measures, such as perceived usefulness and perceived ease of use, using adaptations of Davis' Technology Acceptance Model and Rogers' Diffusion of Innovation theory. Preliminary findings suggest that, on average, drivers are slightly more satisfied with their assigned LDEV than with the available diesel cars. If drivers were able to choose the preferred vehicle the majority of them would favor LDEV.

## 2 - Airline fleet planning with CO2 emission targets under consideration of retrofit options

Karsten Kieckhäfer, Christoph Müller, Thomas Spengler

The global framework for aviation is given by growth expectation (growth rates of 3-5% p.a.) in combination with the challenge to reduce the environmental impact. Especially airlines are under increasing pressure due to ambitious mid- and long-term CO2 reduction targets. To reduce fleet emissions significantly, airlines can purchase new and more fuel efficient aircrafts. However, due to the long use phase of aircrafts, technology improvements in new aircrafts generally take a long time to percolate into the fleet in sufficiently large numbers. Contrary, retrofits at the existing fleet (e.g., winglets) can be a viable alternative in a short to medium timeframe. Decisions on these alternatives are part of airline fleet planning where the development of fleet size and composition is determined. Focusing on the transition towards energy-efficient aviation, we develop a novel optimization model for airline fleet planning. The model determines the fleet composition which maximizes the net present value in the planning horizon under consideration of retrofit options such that a certain CO2 emission target is satisfied. Based on real-world data, the model is applied to two major European airlines (full service network carrier vs. low cost carrier) to study the impact of different CO2 emission targets on the fleet composition. The results indicate that retrofits can make a significant contribution to achieving short term emission targets. The study provides insights for policy makers when setting CO2 emission targets for airlines and developing mechanisms to encourage environmental commitment.

## ■ WB-23

Wednesday, 11:00-12:30 - HFB|B

### CANCELLED: Game Theory and Economics

Stream: Game Theory and Experimental Economics  
Parallel session

Chair: Mark Francis Rogers

## ■ WB-24

Wednesday, 11:00-12:30 - HFB|C

### GOR Dissertation Prize

Stream: Awards  
Parallel session

Chair: Peter Letmathe

## 1 - Anticipation in Dynamic Vehicle Routing

Marlin Wolf Ulmer

Decision making in real-world routing applications is generally conducted under incomplete information. Vehicle dispatchers deal with uncertainty in travel times, service times, customer demands, and customer requests. The information is only revealed successively during the execution of the routing. Technological advances allow dispatchers to adapt their decisions dynamically to new information. Nevertheless, current decisions influence later outcomes. Hence, dispatchers have to anticipate future events in current decision making. Even though the work on dynamic vehicle routing problems (DVRPs) is manifold, anticipatory approaches are still not established. The aim of this work is to give guidance on how to model DVRPs and how to achieve anticipation. For modeling dynamic vehicle routing problems, we propose the use of a Markov decision process (MDP). For the integration of stochasticity in dynamic decision making, methods of approximate dynamic programming (ADP) are established in many applications fields. Until now, the application of ADP-methods to DVRPs is limited due to DVRPs' complexity. We extend and combine general methods of ADP to match the characteristics of DVRPs. A comparison with conventional state-of-the-art benchmark heuristics for a DVRP with stochastic customer requests proves the ADP-methods to be highly advantageous.

## 2 - Game-theoretic Approaches to Allocation Problems in Cooperative Routing

Igor Kozeletskyi

This thesis studies allocation problems arising in horizontal cooperations on the example of cooperative routing problems using the methods of cooperative game theory and operations research. The main contribution of this study lies in the developed methodology to deal with allocation problems in multi-objective cooperative situations with one common objective and individual objectives for all players. This extension leads to an allocation problem, where for every player two payoffs are of importance: the value of his individual utility, and the amount allocated from the common objective. To handle this problem a knowledge from cooperative game theory is extended and two solution concepts, based on the idea of the core and the Shapley value for non-transferable utility games, are developed. For implementation of these concepts two allocation approaches are introduced. Besides this multi-objective scenario a cost allocation problem with an application to cooperative traveling salesman problem is also studied and concepts of the Shapley value and the core are applied. In the implementation of these solution concepts (as well as in the thesis in general) special attention is addressed to the reduction of computational effort combined with them.

## 3 - Methodological Advances and New Formulations for Bilevel Network Design Problems

Pirmin Fontaine

This thesis proposes a Benders decomposition algorithm to solve discrete-continuous bilevel problems to optimality. The efficiency of the method is shown on existing problems from the literature - namely the Discrete Network Design Problem, the Decentralized Facility Selection Problem and the Hazmat Transport Network Design Problem. Depending on the problem structure, the convergence of Benders decomposition is improved by using the multi-cut version or pareto-optimal cuts. For the Discrete Network Design Problem, a linearization of the convex objective function is used and the run time is improved by more than 60% compared to the mixed-integer linear program. Moreover, the Discrete Network Design Problem is extended to a multi-period model for planning maintenance work in traffic networks.

Further, we show on the Decentralized Facility Selection Problem and on the Hazmat Transport Network Design Problem run time improvements of more than 90% compared to the mixed-integer linear program. To include risk equity in hazardous material shipment, a population-based risk definition is introduced and the Hazmat Transport Network Design Problem is extended to a multi-mode model. The numerical results show a better distribution of risk compared to classical models in the literature and a convex relation between risk equilibration and risk minimization.

## 4 - Handling Critical Tasks Online: Deadline Scheduling and Convex-Body Chasing

Kevin Schewior

Completing possibly unforeseen tasks in a timely manner is vital for many real-world problems: For instance, in hospitals, emergency patients may come in and require to be treated, or self-driving cars need to avoid obstacles appearing on the street. Under the hard constraint of timely fulfilling these tasks, one still usually wishes to use resources conscientiously. In this thesis, we develop various online algorithms for handling critical tasks that improve upon previously known bounds on the resource usage, and thereby we answer long-standing questions.

We consider the above applications in the form of two fundamental mathematical problems. First, in online deadline scheduling, jobs arrive over time and need to be scheduled on a machine until their deadline. We present the first algorithm that uses a number of machines bounded in the offline-optimal one, which we complement with an impossibility result when jobs cannot be migrated between machines. Further, we investigate the power of using faster machines. Second, in convex-body chasing, an agent needs to immediately serve tasks located within convex regions and minimize the total travelled distance. We simplify known results and introduce the first competitive algorithms for dimensions larger than two.

## ■ WB-25

Wednesday, 11:00-12:30 - HFB|D

### Market Design, Bidding and Market Zones

Stream: Energy and Environment

Parallel session

Chair: Dominik Möst

Chair: Philipp Hauser

#### 1 - Dynamic programming approach for bidding problems on day-ahead markets

Jérôme De Boeck, Martine Labbé, Étienne Marcotte, Patrice Marcotte, Gilles Savard

In several markets, such as the electricity market, spot prices are determined via a bidding system involving an oligopoly of producers and a system operator. Once time-dependent price-quantity bids are placed by each producer for its production units, the system operator determines a production schedule that meets demand at minimal cost. The spot price charged to the customers is then set to the marginal production cost. Fampa et al. have considered the problem faced by a profit-maximizing producer, whose bids depend on the behaviour of the system operator, as well as the stochastic nature of final demand, and that can be cast within the framework of stochastic bilevel programming. In this presentation, we consider an enhanced model that embeds two key features, namely the uncertainty related to competitors' bids, as well as the impact of spot prices on demand. Our aim is to develop efficient solution algorithms for addressing instances involving a large number of scenarios. Under the assumptions that production costs are linear and that demand is piecewise constant, the bilevel model can be reformulated as a large mixed integer program. Although this problem becomes numerically intractable as the number of scenarios increases, it becomes much simpler when producers are allowed to place different price-quantity bids for a given generator. This relaxation of the original problem can then be solved in polynomial time by a dynamic programming algorithm. This algorithm can then be adapted to heuristically solve the original problem, yielding very quickly feasible solutions characterized by small optimality gaps. The performance of the method has been tested on instances inspired from the Brazilian Electric System National Operator.

#### 2 - Comparative exemplary application of different zonal configuration algorithms for the case of market splitting in Germany

Dirk Hladik, Dominik Möst

As progress is beginning to be made in the coupling of European electricity markets in the midst of increasing shares of renewable energy, congestion management is gaining in importance. One main driver of grid congestion results from inappropriately market zones, in which the underlying grid structure leads to physically infeasible market results. These mounting irregularities are a consequence of the ongoing transformation of the energy system, whereby particular generation capacities are being shifted spatially. Thus, a reconfiguration of market zones remains a much-discussed topic and a number of algorithms are proposed in the extant literature. However, there is no „golden rule“ to determine the optimal zonal configuration. Approaches range from a distinct cluster basis like nodal prices and Power Transfer Distribution Factors (PTDF) to diverse cluster algorithms, time resolutions and different degrees of incorporating uncertainty. This contribution aims to comparatively apply two common approaches based on a hierarchical clustering of nodal prices and PTDF as well as a third, which tries to combine the advantages of both. These three approaches are applied to the German transmission grid where bordering countries are considered as well using the electricity load flow model ELMOD. The current

DE-AT-LU price zone provides a prime application given the current high volumes of curative congestion management. The future increase in wind generation and the nuclear phase-out by 2022 accompanied by delays in grid expansion measures may exacerbate the spatial imbalances. Therefore, this work resolves to determine which one of the three algorithms proves to be preferable to use in the context of market splitting in Germany and assumes a mid-term perspective up to 2025.

#### 3 - Evaluating alternative market designs in electricity markets: a mixed-integer multilevel optimization model and global solution techniques

Thomas Kleinert, Frauke Liers, Martin Schmidt

Mathematical modeling of market design issues in liberalized electricity markets often leads to mixed-integer nonlinear multilevel optimization problems that are intractable in general. Furthermore, no general-purpose solvers exist. We consider the task of simultaneously deciding on network expansion plans, together with the splitting of the market area into a given number of price zones, such that welfare-optimal solutions emerge. This task leads to a challenging multilevel problem that contains a network-design problem and a highly symmetric graph-partitioning model with multi-commodity flow connectivity constraints. Furthermore, proper economic modeling leads to nonlinearities. We develop different problem-tailored solution approaches that yield globally optimal solutions. In particular, we present a KKT transformation approach, an outer approximation approach that exploits strong duality of convex programming, and an approach based on nested generalized Benders decomposition. We present methods for enhancing the solution approach by techniques, such as symmetry breaking and effective primal heuristics. We evaluate the computational behavior on academic and realistic networks. It turns out that our approaches lead to effective solution methods for these challenging optimization tasks arising in electricity markets.

## ■ WB-26

Wednesday, 11:00-12:30 - HFB|Senat

### Bargaining (i)

Stream: Game Theory and Experimental Economics

Parallel session

Chair: Thomas Neumann

#### 1 - An extended fuzzy approach to multicriteria modelling of bilateral bargaining

Tobias Volkmer, Olga Metzger, Thomas Spengler

This paper proposes a bilateral bargaining model under imperfect or vague information combining standard game theoretic solutions with a fuzzy logic based approach. Multicriteria fuzzyfication is used to model individual agent assessments regarding the bargaining situation and the opponent before entering renegotiation rounds. This framework is targeting an analytical solution for optimal concession strategy (output) for the agents using linguistic inputs. Referring to the concept of Constantino and Di Gravio (2009) we reduce the problem to a single-stage case and additionally implement considerations of aspiration adaption theory (Sauer mann and Selten, 1962; Tietz, 1975) into our model. To approach more realistic concession predictions in order to be able to compare our analytical results to the results of potential subsequent experimental studies we use the theory of prominence (Spengler and Vogt, 2008).

References: Constantino, F., Di Gravio, G. (2009). Multistage bilateral bargaining model with incomplete information - A fuzzy approach. *Int. Journal of Production Economics*, 117(2), 235-243. Sauer mann, H., Selten, R. (1962). *Anspruchsanpassungstheorie der Unternehmung*. *Zeitschrift für die gesamte Staatswissenschaft*, 118(4), 577-597. Spengler, T., Vogt, B. (2008). Analyzing numerical responses - A model and its application to examples from personnel and organizational management. *Journal of Neuroscience, Psychology and Economics*, 1(1), 17-32. Tietz, R. (1975). *An Experimental Analysis of Wage Bargaining Behavior*. *Zeitschrift für die gesamte Staatswissenschaft*, 131(1), 44-91.

#### 2 - Bargaining over waiting time in ultimatum game experiments

Roger Berger

While preference-based explanations play an increasing role in economics the accurate measurement of social preferences deserves more attention. Most laboratory experiments measure social preferences by studying the division of "cake that nobody had to bake" (Güth and Kliemt, 2003). We report results of an ultimatum game experiment with bargaining over waiting time. The experiment was created to avoid effects of windfall gains. In contrast to donated money, time is not endowed by the experimenter and implies a natural loss to subjects. This allows for a better measurement of the inherent conflict in the ultimatum game. We implemented three anonymity conditions; one baseline condition, one condition with anonymity among subjects and one double-blind condition in which the experimenter did not know the division of waiting time. While we expected to observe less other-regarding behavior in ultimatum game bargaining over time, our experimental results rather confirm previous ultimatum game experiments, in which people bargained over money. The modal offer was half of the waiting time and only one offer was rejected. Interestingly, anonymity did not change the results significantly. In conclusion, our experiment confirms other-regarding behavior in the ultimatum game.

### 3 - An Experimental Comparison of Ultimatum Bargaining Over Positive, Negative and Mixed Outcomes

*Thomas Neumann, Stephan Schosser, Bodo Vogt*

Experimental economists typically focus on distribution problems that take place in a gains domain. Many real-life situations, e.g. budget allocation within universities or the negotiation of insurance companies over compensation for damages, etc., highlight the relevance of the distribution challenge and also how, in many situations, it is not only positive outcomes that needed to be divided, but also negative or mixed. In this experimental study, we compare the behavior of players in an ultimatum game that takes place in a negative domain with that in a positive domain and with that in a mixed domain. We find that the division of outcomes is different across treatments.

## Wednesday, 13:30-15:00

### ■ WC-01

*Wednesday, 13:30-15:00 - WGS|101*

### Stochastic Integer Programs

Stream: Optimization under Uncertainty

*Parallel session*

Chair: *Tanya Gonser*

#### 1 - Some ideas on integrating lift-and-project cuts into decomposition methods for solving two-stage stochastic programming problems with binary first-stage variables

*Pavlo Glushko, Achim Koberstein, Csaba Fabian*

Lift-and-project cuts are well-known general 0-1 programming cuts which are typically deployed in branch-and-cut methods to solve MILP problems. In this talk, we discuss ways to use these cuts in Benders' type decompositions algorithms for solving two-stage stochastic programming problems with binary first-stage variables. In particular, we show how L&P cuts derived for the mixed-binary first-stage master problem can be integrated into the SP decomposition scheme exploiting second stage information. As a first step of this ongoing research project, we present an adapted L-shaped algorithm, the envisaged implementation based on the existing solver system PNBsolver and an illustrative example.

#### 2 - Reliable single allocation hub location problem under hub breakdowns

*Nicolas Kämmerling, Borzou Rostami, Christoph Buchheim, Uwe Clausen*

The design of hub-and-spoke transport networks is a strategic planning problem, as the choice of hub locations has to remain unchanged for long time periods. However, strikes, disasters or traffic breakdown can lead to the unavailability of a hub for a short period of time. Therefore it is important to consider such events already in the planning phase, so that a proper reaction is possible; once a hub breaks down, an emergency plan has to be applied to handle the flows that were scheduled to be served by this hub. In this paper, we develop a two-stage formulation for the single allocation hub location problem which includes the reallocation of sources to a backup hub in case the hub breaks down. In contrast to related problem formulations from the literature, we keep the non-linear structure of the problem in our model. A branch-and-cut framework based on Benders decomposition is designed to solve large scale instances to proven optimality. Thanks to our decomposition strategy, we keep the structure of the resulting formulation similar to the classical single allocation hub location problem, which in turn allows to use classical linearization techniques from the literature. Our computational experiments show that this approach leads to a significant improvement in the performance when embedded into a standard mixed-integer programming solver.

#### 3 - A Branch-and-Bound Approach for Multi-Stage Stochastic Mixed-0-1 Programs

*Tanya Gonser, Stefan Nickel, Francisco Saldanha-da-Gama, Iris Heckmann*

In this talk we present a new exact algorithmic framework for solving multi-stage stochastic mixed 0-1 problems based on a branch-and-bound approach. The approach can be applied to multi-stage problems with mixed-integer variables and uncertainty in each time stage.

We assume that uncertainty can be captured by a finite set of scenarios. We describe the underlying scenario tree with a unique set of indices that enables an easy reformulation of the deterministic equivalent model. In turn, the latter is rewritten in a splitting variable representation model allowing an explicit description and subsequent relaxation of the non-anticipativity constraints. We show that the optimal solution of the deterministic equivalent can be formulated as a weighted average of the optimal decisions obtained in the corresponding scenarios within the splitting variable representation. This implies that an LP relaxation of the deterministic equivalent equals a relaxation of the corresponding non-anticipativity constraints in the splitting variable representation.

Computational results are presented for risk-aware capacitated facility location problems with multiple stages as well as uncertain demand

and capacities. The results show that the presented method leads to the optimal solution for all considered instances with a good performance.

## ■ WC-02

Wednesday, 13:30-15:00 - WGS|102

### Modeling Systems II

Stream: Software Applications and Modelling Systems  
*Parallel session*

Chair: *Mike Steglich*

#### 1 - Building and Solving Optimization Models with Python

*Kostja Siefen*

Python is a powerful and well-supported programming language that's also a good choice for mathematical modeling. It has special features that make it easy to build and maintain optimization models. The Gurobi Python interface combines the ease and expressiveness of a modeling language with the power and flexibility of a programming language. In this talk we will show how to build large-scale, high-performance optimization applications through an interactive development process involving actual models as examples.

#### 2 - Embedded Code in GAMS - Using Python as an Example

*Lutz Westermann*

This talk is about a recent extension of the General Algebraic Modeling System (GAMS): The "Embedded Code" facility.

GAMS uses relational data tables as a basic data structure. With these, GAMS code for parallel assignment and equation definition is compact, elegant, and efficient. However, traditional data structure (arrays, lists, dictionaries, trees, graphs, ...) are not natively or easily available in GAMS. Though it is possible to represent such data structures in GAMS, the GAMS code can easily become unwieldy, obfuscating, or inefficient. Also, in the past it was not easy to connect libraries for special algorithms (e.g. graph algorithms, matrix operations, ...) to GAMS without some data API knowledge (GDX) and some disk I/O.

To overcome these issues, the Embedded Code facility was introduced recently. It allows the use of external code (e.g. Python) during compile and execution time. GAMS symbols are shared with the external code, so no communication via disk is necessary. It provides a documented API and additional source code for common tasks so that the user can concentrate on the task at hand (e.g. computing shortest paths) and not the mechanics of moving data in and out of GAMS.

#### 3 - Optimization Modelling for Data Scientists in IBM Data Science Experience

*Sebastian Fink, Hans Schlenker*

More and more companies rely on data scientists to turn company data into real business value. Data scientists explore and excavate business data, extract valuable data sets, combine them with 3rd party data, and apply the most advanced analytics approaches to the data to derive real and often very precious business value from that data. Data scientists typically use methods such as data mining, visualization, or machine learning. Mathematical optimization is not yet widely used in this community, but this can be changed: Powerful language APIs for solvers like CPLEX, for data scientist's preferred programming languages, and their integration into data science tools, simplify the usability of math programming for data scientists. This not only adds yet another technology to the data scientist's toolsets, but it also empowers them to build much richer analytics pipelines, allowing them to combine optimization with approaches like forecasting, segmentation, or classification. In this talk we present: How Python and Notebooks can be used together with CPLEX to build full math programming and constraint programming models, how this can be used to model and solve real world optimization problems, and how these models can be analyzed and validated in public, hybrid and private cloud environments.

#### 4 - Implementing and solving decision problems with SolverStudio/Cmpl and CmplServer

*Mike Steglich*

Companies or other organisations which are faced with decision problems to be solved using operations research methods have to imbed them in their ICT systems.

This talk shows how open-source software tools like SolverStudio/Cmpl and CmplServer can be used by presenting real examples. SolverStudio is an add-in for Excel on Windows that allows to build and solve optimisation models in Excel using selected modeling languages. One of the languages is CMPL (<Coliop|Coin> Mathematical Programming Language).

After an overview of the main functionalities of SolverStudio, the main aspects of CMPL's integration with SolverStudio will be described.

Real decision problems often need to be solved on high-performance hardware but controlled on a notebook or desktop computer. Therefore, it will be shown how CMPL models can be solved using CmplServer which is an XML-RPC-based web service for distributed and grid optimization.

## ■ WC-03

Wednesday, 13:30-15:00 - WGS|103

### Cancelled: Terminal Operations

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: *Ann-Kathrin Lange*

## ■ WC-04

Wednesday, 13:30-15:00 - WGS|104

### Online Optimization

Stream: Graphs and Networks  
*Parallel session*

Chair: *Yann Disser*

#### 1 - Tight Competitive Analysis for Online TSP on the Line

*Miriam Schlöter, Yann Disser, Jan Hackfeld, Christoph Hansknecht, Kevin Schewior, Leen Stougie, Antje Bjelde, Julie Meißner, Maarten Lipmann*

We consider the online traveling salesperson problem (TSP), where requests appear online over time on the real line and need to be visited by a server initially located at the origin. We distinguish between closed and open online TSP, depending on whether the server eventually needs to return to the origin or not. While online TSP on the line is a very natural online problem that was introduced more than two decades ago, no tight competitive analysis was known to date. We settle this problem by providing tight bounds on the competitive ratios for both the closed and the open variant of the problem. In particular, for closed online TSP, we provide a 1.64-competitive algorithm, thus matching a known lower bound. For open online TSP, we give a new upper bound as well as a matching lower bound that establish the remarkable competitive ratio of 2.04. Additionally, we consider the online Dial-A-Ride problem on the line, where each request needs to be transported to a specified destination. We provide an improved non-preemptive lower bound of 1.75 for this setting, as well as an improved preemptive algorithm with competitive ratio 2.41. Finally, we generalize known and give new complexity results for the underlying offline problems. In particular, we give an algorithm with running time  $O(n^2)$  for closed offline TSP on the line with release dates and show that both variants of offline Dial-A-Ride on the line are NP-hard for any capacity  $c \geq 2$  of the server.

#### 2 - Anonymous Graph Exploration with Binoculars

*Jérémie Chalopin*

We investigate the exploration of networks by a mobile agent. It is long known that, without global information about the graph, it is not possible to make the agent halts after the exploration except if the graph is a tree. We therefore endow the agent with binoculars, a sensing device that enables the agent to see the graph induced by its neighbors. We

show that, with binoculars, it is possible to explore and halt in a large class of non-tree networks. We give a complete characterization of the class of networks that can be explored using binoculars using standard notions of discrete topology. This class is much larger than the class of trees: it contains in particular chordal graphs, plane triangulations and triangulations of the projective plane. Our characterization is constructive: we present an Exploration algorithm that is universal; this algorithm explores any network explorable with binoculars, and never halts in non-explorable networks.

### 3 - Online bipartite matching in offline time

*Anna Zych-Pawlewicz, Bartłomiej Bosek, Dariusz Leniowski, Piotr Sankowski*

A bipartite graph  $G$  between  $n$  clients and  $n$  servers is revealed online. The clients arrive in an arbitrary order and request to be matched to a subset of servers. In our model we allow the clients to switch between servers and want to maximize the matching size between them, i.e., after a client arrives we find an augmenting path from a client to a free server. Our goals in this model are twofold. First, we want to minimize the number of times clients are reallocated between the servers. Second, we want to give fast algorithms that recompute such reallocation. As for the number of changes, we propose a greedy algorithm which for each server has its client reassigned  $O(\sqrt{n})$  times. This gives an  $O(n^{3/2})$  bound on the total number of changes, what gives a progress towards the main open question risen by Chaudhuri et al. (INFOCOM'09) who asked to prove  $O(n \log n)$  upper bound. We also show that by introducing proper amortization we can obtain an incremental algorithm that maintains the maximum size matching in total  $O(\sqrt{nm})$  time. This matches the running time of one of the fastest static maximum matching algorithms that was given by Hopcroft and Karp (SIAM J. Comput '73).

## ■ WC-05

*Wednesday, 13:30-15:00 - WGS|104a*

### Car Pooling & Sharing

Stream: Traffic, Mobility and Passenger Transportation  
*Parallel session*

Chair: *Tai-yu Ma*

#### 1 - Carpool formation along high-occupancy vehicle lanes

*Stefan Schwerdfeger, Nils Boysen, Dirk Briskorn, Konrad Stephan*

High-occupancy vehicle lanes are restricted traffic lanes reserved for vehicles with multiple car occupants. Depending on the current number of passengers a driver has to either travel slower on the general purpose lane or is allowed to access the faster HOV lane. This paper treats optimization approaches for matching supply and demand when building carpools along HOV lanes. In current applications, carpools are rather spontaneously formed at slugging areas where potential passengers queue up. Internet-enabled mobile phones, however, allow for dynamic carpool formation based on sophisticated scheduling procedures. We investigate different versions of the carpool formation problem. An in-depth analysis of computational complexity is provided and suited solution procedures are developed. These procedures are then applied to quantify the benefit of an optimized carpool formation process. In a comprehensive computational study we compare our optimization approaches with spontaneous ride sharing.

#### 2 - Optimal Integration of Autonomous Vehicles in Car Sharing

*Marcus Kaiser*

This work is about the potential impact of autonomous vehicles on car sharing. More specifically, estimations on the change of necessary fleet size and of arising cost are given compared to the current situation. For that purpose, a deterministic model relying on historical data of customers' car rentals is created. The resulting mixed-integer linear program is the extension of a vehicle scheduling problem by the possibility of refueling for the vehicles and the consideration of public transport. The focus then lies on an alternative formulation gained by a Dantzig-Wolfe decomposition, and an exact solution method based on branch-and-price. This involves the examination of a column generation using a heuristic as well as an exact algorithm for the emerging subproblems.

### 3 - Dynamic bi-modal ridesharing using optimal passenger-vehicle assignments

*Tai-yu Ma*

Existing mobility-on-demand service has a major inefficiency for its operating policy design by disregarding the opportunity in cooperation with other transportation networks. In this work, a dynamic bi-modal vehicle dispatching and routing algorithm is proposed to address real-time operating policy of ride-sharing (feeder) services with the presence of other public transportation networks. We consider a real-time on-demand feeder service supported by one operator. The operator uses a fleet of homogeneous capacitated vehicles and designs its routing and dispatching policy. The addressed problem is a typical first/last mile problem. We propose an optimal passenger-vehicle assignment algorithm based on the concept of shareability graph (Alonso-Mora et al; 2017). Firstly, we compute which requests can be pairwise combined and which vehicles can serve the requests by satisfying the constraints in terms of passengers' maximum waiting time, maximum delay and vehicles' capacity. We combine possible pre-/post-transit trip requests as groups based on the pairwise request-vehicle graph. Then we compute which feasible trips (a set of requests) can be served by which vehicles. Finally, optimal trip-vehicle assignment is determined by solving an integer linear program problem. Efficient rebalancing strategy for idle vehicles is proposed to reduce users' waiting times. The numerical study is conducted on a realistic bi-modal transportation network located in Luxembourg and cross-border area. We test the influence of demand intensity, fleet size, waiting time on passengers' delay and on vehicle occupancy rates. The proposed methods can be applied to operating policy design of mobility-on-demand service to increase the utilization of public transportation service.

## ■ WC-06

*Wednesday, 13:30-15:00 - WGS|105*

### Selected Topics

Stream: Graphs and Networks

*Parallel session*

Chair: *Stephan Westphal*

#### 1 - On a technique of finding running tracks of specific length in a road network

*David Willems, Stefan Ruzika, Oliver Zehner*

Many sport events, especially endurance sport competitions, take place in urban spaces. In the past years, fun runs or obstacle runs gained public attention with growing participant numbers. Labels like XLETIX, Tough Mudder, Strongman, Münz Sportkonzept or B2Run emerged due to the popularity of such events. For example, 17,500 athletes are expected to participate in the upcoming Münz Firmenlauf in Koblenz. For a mid-sized city like Koblenz, this constitutes an immense interference into traffic for each afternoon the run is being carried out. Often, those competitions are reoccurring on an annual basis and have grown to an extent that their running track disrupts the local traffic situation. Traffic participants may encounter road closures and long waiting times. Until now, event organizers have to propose a potential track at the corresponding municipal administration office. This includes technical details as start and finish point as well as legal requirements for the track. In this talk, we address the problem of finding a path of given length in a network, examine its complexity and present a pseudopolynomial algorithm to solve the problem. Especially organizers of running events benefit from this method of finding such paths and cycles as this algorithm is applicable to road networks. As a result, this approach constitutes a simplification tool in the decision-making process of finding adequate running tracks. Since the algorithm returns various paths, it is possible for an organizer to choose the track that meets most desired requirements either by hand or by the application of an additional step of optimization.

#### 2 - A simulation-based framework for competitive analysis of online scheduling problems

*Martin Dahmen*

A common scheduling problem is given by a set of jobs that must be assigned to a set of machines and different timeslots, under the restriction of various constraints. In our case, we add an additional online characteristic to our scheduling problems. This means that jobs will appear subsequently and as soon as a job appears an online algorithm has to decide which machine it will be assigned to, without knowledge



of what the rest of the sequence looks like. The objective of online optimization is to find an online strategy, or in most cases an algorithm that best solves the online problem in the worst-case scenario. The challenge of worst-case and competitive analysis is to deal with a large number of possible strategies and scenarios that have to be examined. As part of this project, we present an optimization framework that combines theoretical principles of mathematical optimization with practice-oriented analytic methods of simulation to solve worst-case problems in terms of online scheduling. We use an iterative approach to create and update a set of best-known worst-case sequences with the help of genetic algorithms. We further use pattern recognition and cluster analysis to learn about the structure of worst-case sequences and to improve the search methods of the genetic algorithms by this means. Experimental results show that genetic operators are an efficient and effective approach to improve any convergence behavior of many different scheduling problems. In almost all studied cases the framework converged to the best-known bounds that have been found by means of theoretical analysis so far.

## ■ WC-07

Wednesday, 13:30-15:00 - WGS|106

### Various Aspects of Discrete Models

Stream: Discrete and Integer Optimization

Parallel session

Chair: Steffen Goebbels

#### 1 - Mathematische Optimierung in der Schule

Alexander Schulte

Lineare und Ganzzahlige Programmierung als Teil der mathematischen Optimierung sind ein wichtiges Teilgebiet des Operations Research und damit der angewandten Mathematik. Im bundesdeutschen schulischen Bildungsplan sucht man mathematische Optimierung hingegen nahezu vergeblich. In diesem Vortrag wird ein bereits erprobtes Unterrichtsvorhaben vorgestellt, welches Schülerinnen und Schülern einen anschaulichen Zugang zur mathematischen Optimierung ermöglicht.

Das vorgestellte Unterrichtsbeispiel, konzipiert für die Jahrgangsstufe 9/10, führt anhand des bekannten Sudoku-Rätsels in die Ganzzahlige Programmierung ein. Ein Schwerpunkt liegt dabei auf der Vermittlung von authentischen wissenschaftlichen Arbeits- und Denkweisen. Die Einführung in die (ganzzahlige) mathematische Modellbildung erfolgt durch die Entwicklung eines ganzzahligen Modells von Sudoku (vgl. Kaibel/Koch, 2006) sowie die Herleitung gängiger Bestandteile von Baumsuchalgorithmen (Propagierung, Probing, Branching). In einer Phase der selbstständigen Forschung gehen die Lernenden darüber hinaus selbst gestellten Fragen nach, beispielsweise wie Spezialregeln das Modell und die eindeutige Lösbarkeit beeinflussen. Durch den forschenden Ansatz findet ein produktiver Umgang mit dem Thema statt, der zu einem tiefen Verständnis für die elementaren Prinzipien der mathematischen Optimierung führt.

Auf Grundlage des vorgestellten Unterrichtsvorhabens diskutieren wir, inwiefern Fachwissenschaft und Schule von einem frühen Umgang mit diesem Thema in der Schule profitieren können. Darauf aufbauend wird abschließend ein Ausblick gegeben, wie das Thema mathematische Optimierung helfen kann, in der Schule ein realistisches Bild von angewandter Mathematik zu vermitteln.

#### 2 - A Linear Program for Matching Photogrammetric Point Clouds with CityGML Building Models

Steffen Goebbels, Regina Pohle-Fröhlich, Philipp Kant

We match photogrammetric point clouds with 3D city models in order to texture their wall and roof polygons. Point clouds are generated by the Structure from Motion (SfM) algorithm from overlapping pictures and films that in general do not have precise geo-referencing. Therefore, we have to align the clouds with the models' coordinate systems. We do this by matching corners of buildings, detected from the 3D point cloud, with vertices of model buildings that are given in CityGML format. Due to incompleteness of our point clouds and the low number of models' vertices, the standard registration algorithm "Iterative Closest Points" does not yield reliable results. Therefore, we propose a relaxation of a Mixed Integer Linear Program that first finds a set of correspondences between building model vertices and detected corners. Then, in a second step, we use a Linear Program to compute an optimal linear mapping based on these correspondences.

## ■ WC-08

Wednesday, 13:30-15:00 - WGS|107

### Public Transportation Planning 1

Stream: Traffic, Mobility and Passenger Transportation  
Parallel session

Chair: Anita Schöbel

#### 1 - Optimizing the Line System of Karlsruhe

Ralf Borndörfer, Marika Karbstein, Petra Strauß

Karlsruhe is currently undergoing major construction projects in its inner city. These lead to changes that heavily affect the public transportation system. In 2016, a project "Konbiverkehr 2020" to devise and evaluate possible future designs using mathematical optimization methods was started by Verkehrsbetriebe Karlsruhe, the traffic consulting companies ptv and TTK, and the research institute ZIB. This talk reports about this project and its results.

#### 2 - A Local Search Heuristic for Integrated Train Shunting and Service Scheduling

Roel van den Broek, Han Hoogeveen, Marjan van den Akker

Trains have to be maintained and cleaned regularly to ensure passenger safety and satisfaction. These service tasks must be performed outside the rush hours, when the trains are parked off the main railway network on shunting yards. To achieve a smooth operation of the shunting yard, daily plans are constructed in advanced based on the current time table of arriving and departing trains. Planners have to match incoming train units to positions in the outgoing trains, schedule the service tasks, assign trains to parking tracks and route the trains over the location. The strong interdependence of the plan components as well as the natural restrictiveness of train movements lead to a highly constrained planning problem that combines the Train Unit Shunting Problem (TUSP) with features of classical Resource Constrained Project Scheduling Problems (RCPSPs). To find feasible solutions, we propose a local search approach that operates on a graph-based model of a plan that integrates all the different planning aspects. The performance of several variants of this heuristic are investigated in a case study for the Dutch Railways (NS).

#### 3 - A heuristic for integrated public transportation planning

Anita Schöbel, Julius Pätzold, Philine Schiewe, Alexander Schiewe

The traditional approach in public transportation planning follows a fixed sequence of planning steps: First a line concept is calculated, then a timetable is chosen, and finally a vehicle schedule is planned. One of the problems which may arise in this setting is that the lines in the first step are not created with the awareness that vehicle schedules will be planned on them. It is possible to formulate the integrated problem as integer program, but even for very small instances its solution is too time-consuming. Instead, we present a heuristic to overcome this problem. The basic idea is to create lines with an overall duration of a multiplicity of the planning period (or slightly less). We introduce a vehicle scheduling procedure that arranges vehicle trips on this line concept which consist of circulation activities with small durations and therefore small costs. These vehicle schedules can be obtained before a timetable has to be chosen. To retrieve a timetable we present an algorithm that is specifically designed to solve instances with already existing dependencies between lines. It does so by minimizing the change durations of passengers and hence their traveling times. Preliminary computational results in LinTim, our software framework for public transportation planning, suggest that this heuristic can find a solution which is both, passenger convenient and cost efficient in much shorter time than the traditional approach.

## ■ WC-09

Wednesday, 13:30-15:00 - WGS|108

### Travelling and Shipping

Stream: Discrete and Integer Optimization

Parallel session

Chair: Achim Hildenbrandt

## 1 - A modified Benders method for the single and multiple allocation p-hub median problem

Hamid Mokhtar, Mohan Krishnamoorthy, Andreas Ernst

We consider the well-known uncapacitated p-hub median problem with multiple allocation (UMApHMP), and single allocation (USApHMP). These problems have received significant attention in the literature because while they are easy to state and understand, they are hard to solve. They also find practical applications in logistics and telecommunication network design. Due to the inherent complexity of these problems, we apply a modified Benders decomposition method to solve large instances of the UMApHMP and USApHMP. The Benders decomposition approach does, however, suffer from slow convergence mainly due to the high degeneracy of subproblems. To resolve this, we apply a novel method of accelerating Benders Method. Our approach outperforms existing results in the literature by more appropriately choosing parameters for the accelerated Benders method, and by solving subproblems more efficiently using minimum cost network flow algorithms. We implement our approach on well-known benchmark data sets in the literature and compare our computational results with existing results. The computational results confirm that our approach is efficient and enables us to solve larger single- and multiple-allocation hub median instances.

## 2 - Variants of the Traveling Salesman Problem with additional ordering constraints

Achim Hildenbrandt

The traveling salesman problem (TSP) is probably the most studied problem in combinatorial optimization. In the field of disaster logistics you often face tasks which can be modeled as a TSP with additional ordering constraints. In this talk we therefore want to consider four different variants of the TSP. The first one is Clustered TSP (CTSP) where all nodes are partitioned into clusters and all nodes of one cluster have to be visited in a row. The second one is the ordered clustered TSP (OCTSP) which is a CTSP where an additional ordering in which the clusters must be visited is given. We also want to consider the precedence constrained TSP (PCTSP) where we are given a list of mandatory precedence relations telling which node must be visited before which other. The last problem is the target visitation problem where an additional preference matrix is given. The objective cost of a tour is then computed as the difference of all fulfilled preferences and the traveling costs. For each of these four problems we discuss different IP models and examine the connections between them. We also want to present a branch-and-cut algorithm which can solve these problems to optimality. For the TVP a new way of solving is presented which uses lazy cuts.

are able to continuously 'learn' by interacting with the unknown environment. We compare reinforcement learning techniques to problem-specific heuristics, and show how problem-specific heuristics can enhance the learning process by guiding the exploration of the state-action space. We suggest both new competitive approaches for solving large-scale DCRP instances, as well as flexible approaches which allow to account for possible online extensions. In particular we consider three algorithms: Q-learning, Monte Carlo Tree Search and an extension of the well-known Beam Search approach from literature. In our computational experiments we first benchmark our solvers against the traditional literature instances. Then we suggest new benchmarking instances and compare our solvers on this new benchmark set.

## 2 - A Mixed-Integer Linear Program for the Traveling Salesman Problem with Structured Time Windows

Christian Truden, Philipp Hungerländer

The NP-hard Traveling Salesman Problem with Time Windows (TSPTW) is concerned with visiting a set of customers within their assigned time windows such that a given objective function is minimized. The TSPTW has several applications in its own right and additionally also appears as subproblem within the more general capacitated Vehicle Routing Problem with Time Windows (cVRPTW).

We introduce the Traveling Salesman Problem with structured Time Windows (TSPsTW). The difference between the TSPsTW and the standard TSPTW is the special structure of the time windows: structured time windows can hold several customers and are non-overlapping.

This special structure of the time windows is motivated by an online grocery shopping application in the context of a large international supermarket chain that builds their vehicle's tours as new customers come in. In this application, the structure of the time windows is set by the supplier who provides the customer with a selection of time windows to choose from. Hence in this application, these special structural features neither impose substantial restrictions to the supplier nor to the customer.

We suggest a simple but nonetheless very efficient mixed-integer linear program (MILP) for the TSPsTW that can be easily and quickly implemented by practitioners. Finally in a computational study we showcase that our MILP is highly competitive compared to our MILPs for the TSPTW from the literature.

## 3 - On the Slot Optimization Problem in On-Line Vehicle Routing

Philipp Hungerländer, Andrea Rendl, Christian Truden

The capacitated vehicle routing problem with time windows (cVRPTW) is concerned with finding optimal tours for vehicles that deliver goods to customers within a specific time slot (or window), respecting the maximal capacity of each vehicle. The on-line variant of the cVRPTW arises for instance in online shopping services of supermarket chains: customers choose a delivery time slot for their order online, and the fleet's tours are updated accordingly in real time, where the vehicles' tours are incrementally filled with orders.

In this paper, we consider a challenge arising in the on-line cVRPTW that has not been considered in detail in the literature so far. When placing a new order, the customer receives a selection of available time slots that depends on his address and the current (optimized) schedule. The customer chooses his preferred time slot, and his order is scheduled. The larger the selection, the more likely the customer finds a suitable time slot, leading to higher customer satisfaction and a higher overall number of placed orders. We denote the problem of determining the maximal number of feasible time slots for a new order as the Slot Optimization Problem.

We propose several heuristics for both determining feasible and infeasible slots. Our approaches combine local search techniques with strategies to overcome local minima and integer linear programs for selected sub-problems. In an experimental evaluation, we demonstrate the efficiency of our approaches on a variety of benchmark sets and for different time restrictions that are motivated by varying customer request rates.

## ■ WC-10

Wednesday, 13:30-15:00 - WGS|108a

## New Solution Approaches for Applications from Real-World Projects (i)

Stream: Discrete and Integer Optimization

Parallel session

Chair: Anja Fischer

## 1 - A comparison of reinforcement learning and heuristics for the Dynamic Container Relocation Problem

Paul Alexandru Bucur, Philipp Hungerländer

In maritime port operations there exist areas, known as storage bays, in which containers are stacked in tiers on top of each other in several columns. In such a storage system, containers may only be retrieved one-by-one if they are the highest in their column. In the Container Relocation Problem (CRP), given an initial configuration of the bay and an a-priori known departure sequence, the goal is to retrieve the wanted containers in the predefined order, while keeping the number of container relocations inside the bay to a minimum. The Dynamic Container Relocation Problem (DCRP) introduces a dynamic aspect by also considering arriving containers. In our presentation we explore the use of problem-specific heuristics and reinforcement learning for the DCRP. The main advantage of reinforcement learning techniques is that they do not necessarily require a model of the problem. Hence they

## ■ WC-11

Wednesday, 13:30-15:00 - WGS|005

### Liner Shipping Optimization II

Stream: Logistics and Freight Transportation

Parallel session

Chair: Stefan Guericke

#### 1 - Towards Dynamic Pricing in Liner Shipping with Accurate Vessel Capacity Models

Mai Ajspur, Rune Jensen

A recent study by McKinsey estimates a loss in liner shipping due to non-dynamic pricing of more than \$4B per year. A challenge for introducing dynamic pricing, however, is that the free capacity of a container vessel is highly dependent on the composition of the type of containers to stow. For example, stowing many light reefer-containers often makes it impossible to stow heavier containers, even if it is within the ship's nominal capacity w.r.t. TEU, reefer slots and weight. Capacity models that accurately describe the feasible cargo compositions are therefore needed; these can then be applied in cargo flow simulations used to compute the residual capacity of the shipping network, which is the basis for dynamic pricing. In this work, we address the described problem by deriving accurate and compact capacity models from the detailed but large linear stowage optimization models recently published by Delgado et al.. This is done by abstracting away the unneeded information, such as the specific location of each container in the cargo. For this purpose, we have developed a hierarchically decomposed and parallel version of the Fourier-Motzkin elimination method, which projects the feasible solutions in a large dimensional space into a space of smaller dimension. Our results show that our projected models are two orders of magnitude smaller than the initial stowage models and makes the cargo flow simulations more scalable without significant loss of accuracy. Further, we obtain more accurate results compared to only using upper bounds on the nominal TEU, weight and reefer-capacities, which is what currently is done.

#### 2 - Uptake Management in Liner Shipping - Industry Challenges and a Solution Approach

Stefan Guericke

Today, more than 6000 active container vessels enable the global merchandise trade. Out of these, the majority of assets are deployed on liner services, steaming on a fixed route to serve uncertain customer demands. This results in high fix costs to operate the network and in perishable capacities on which customers can place competing bookings. Carriers operating these services face a planning problem to decide which cargo to pick to maximize yield, called uptake management in liner shipping. In other industries, such as the airline industry, this problem is called Revenue or Yield Management and is well studied in theory and practice for several decades. However, research and application of these well known techniques from other industries are still relatively sparse in liner shipping. The contribution of this work is twofold: First, uptake management is described from a practical perspective of globally operating carriers, indicating the challenges of applying existing research to liner shipping and raise awareness of uptake management in the research community. Second, the well-studied Expected Marginal Seat Revenue method, originally developed for airline passenger industry, is adopted and applied to liner shipping for the first time. Preliminary results are presented for an example vessel departure showing both the challenges, but also the applicability of Revenue Management techniques in liner shipping.

## ■ WC-12

Wednesday, 13:30-15:00 - WGS|BIB

### Business Track II

Stream: Business Track

Parallel session

Chair: Alexander Bradler

#### 1 - Strategic network analytics for the postal industry

Patrick Briest, Ingmar Steinzen

Advanced analytics are permeating almost all aspects of network operations of postal and logistics companies and result in significant improvements in planning accuracy and agility. A vast number of both off-the-shelf and proprietary tools exist to support most aspects of day-to-day operations from depot-level volume forecasting to sort center yard management or dynamic delivery route planning. Interestingly, however, there seems to remain a last bastion within most companies that hasn't been taken by analytics by storm yet - that of long-term strategy making. Many times, decisions on significant real-estate investments, long-term contracts or regulatory issues are taken with little consideration of complex resulting effects on network operating cost, service quality implications or agility to support an evolving product portfolio (moving, e.g., into time-window or same day delivery). Is this because existing tools aren't suited to fully support strategic decision processes? What would be needed in terms of tools, capabilities and processes to bring truly analytics driven decision making into postal board rooms? In our talk, we will briefly outline strategic challenges most postal networks will face (or are already facing) in a world of ever-growing and diversifying eCommerce, globalizing trade flows and increasing competition. We will then argue that a new and different kind of analytics will be needed to address these challenges and allow decision makers to understand their networks as core strategic assets rather than a complexity to be dealt with. Finally, we'll provide a brief overview of CEP2NET powered by OPTANO, McKinsey's proprietary and tailored solution for postal network analytics.

#### 2 - Delivering on delivery: Optimisation and the future of vehicle routing

Adam West, Paul Hart, Christina Burt

As the demand for home delivery continues to grow, so too does the need for organisations to implement more efficient delivery operations. For our clients, the constraints imposed on home delivery are numerous - and it is a challenge that causes many organisations to struggle. Our clients have any number of vehicles, each with limited capacity. Vehicles are limited to certain routes, and routes are often limited by traffic, accidents or road closures. Add driver shifts, multiple destinations and the rising desire for nominated time-window delivery (slots) and you get a scheduling problem no human operator can solve with any degree of accuracy. Our data-driven, operations research approach has, and will continue to improve the efficiency of home delivery; reducing costs for our clients, and vastly improving the customer experience.

In this talk, as well as discussing the above in more depth, we will describe how optimisation and machine learning can be leveraged to build highly impactful last-mile delivery solutions. We will illustrate, through case studies from our own consulting experiences, how some of the UK's largest retailers are using optimisation to schedule their fleets of vehicles, and disclose just how impactful it has been for their costs, and their customers. We will provide an insight into the business challenges associated with applying the latest optimisation techniques into organisations of all sizes, and describe how the rising expectations of customers is forcing the optimisation community to react.

#### 3 - User-centered Smart Data - Decision Analytics for Digital Engineering

Alexander Bradler, Alexander Paar, Stephan Blankenburg

Currently, the strategic use of Big Data for decision analytics is a challenge of utmost relevance for numerous leading enterprises. Following a clear management commitment, most companies have prepared themselves with a considerable IT infrastructure to meet the challenges of data-driven decisions. However, there is often a serious discrepancy between the technical possibilities for intelligent use of Big Data and its actual application for immediately available use cases. This gap can very often be contributed to the lack of organizational development. In order to tap the full potential in the long term, it is not enough to rely on the know-how of data scientists in the short term. In the future, engineers will have to act as data scientists themselves. Hence, a mindset change and corresponding qualification measures are essential. In this talk, we present the iterative and incremental User-centered Smart Data approach for effective decision analytics. This innovative Design Thinking based methodology involves users and their needs right from the start and rapidly develops highly scalable data analyses in an agile manner and conforming to the respective IT policies. The resulting speedboats in form of prototypes enable sustainable solutions accepted by central IT departments. Customized training concepts provide the required backwind for the necessary mindset change of the engineers. Concrete case studies show how the existing gap between IT and specialist departments is closed and data based and algorithmically sound decision-making processes can be established efficiently. For example, for a premium automobile OEM, the application of User-centered Smart Data facilitated the optimization of the operating strategy of hybrid drives to maximize recuperation performance.

#### 4 - Designing and optimizing an LNG supply chain using LocalSolver

*Clément Pajean*

This talk deals with the optimization of the sizing and configuration of a Liquefied Natural Gas (LNG) supply chain. This problem is encountered at ENGIE, a French multinational electric utility company which operates in the fields of electricity generation and distribution, natural gas and renewable energy. Having described the industrial problem and its stakes, we show how to model and solve it efficiently using set-based modeling features of LocalSolver, a new-generation hybrid mathematical programming solver. In the process, we combined ENGIE Lab CRIGEN business knowledge and mathematical modelling skills with LocalSolver agile design thinking and powerful solver components to tackle advanced routing & scheduling problems. The resulting software OptiRetail is now used by ENGIE to carry out design studies of LNG supply chains. Several onshore customers need to be supplied with natural gas from LNG sources. The demand of each client is known for every time step. Different transportation means such as vessels or trucks are available to supply LNG from sources to customers, possibly using intermediate hubs. Each carrier is characterized by its storage capacity and its costs as well as the list of sites that it can visit. A tour is a distribution travel starting from a source with full capacity and visiting a certain number of sites, unloading a fraction of the capacity at each site, and finally getting back to the starting source. A planning is a set of tours over the horizon. The cost of the planning is composed of fixed costs and operating costs. The objective is to minimize this cost over a long-term horizon, typically 20 years.

## ■ WC-13

Wednesday, 13:30-15:00 - RVH|I

### Forecasting Energy and Commodities

Stream: Business Analytics, Artificial Intelligence and Forecasting

*Parallel session*

Chair: *Ralph Grothmann*

Chair: *Sven F. Crone*

#### 1 - Short-term zero flow forecasting in gas networks

*Milena Petkovic*

Natural gas is the cleanest fossil fuel since it emits the lowest amount of CO<sub>2</sub>. Over the years, lower prices and better infrastructure lead to significant increase of natural gas usage in transportation, residential and industrial sectors. Accurate forecasting of natural gas flows is crucial for maintaining gas supplies, transportation and network stability. The main goal of the work we present is to compute accurate forecast for zero gas flow for the 24 upcoming hours in order to support other forecasting methods and, furthermore, operational decisions. The proposed methodology for dealing with the problem of short-term natural gas flows forecasting in gas transmission networks for nodes with high percentage of zero flow hours is based on Nonlinear Autoregressive Network with exogenous inputs (NARX). We used NARX neural network with 24 outputs which represent the prediction of 24 hours of gas flow. For exogenous inputs several different parameters were chosen based on a sensitivity analysis. The errors of forecast calculated as accuracy of predicting occurrence of zero flows one-day ahead shown to be on a very small level so we concluded the proposed methodology can be used for supporting other forecasting methods.

#### 2 - Wind power forecasting using Gaussian process state-space models

*Tobias Jung*

Accurately forecasting the power generated by a wind farm at day-ahead and intraday timescales is the key problem owners and operators of wind farms face and necessary for trading, dispatch, but potentially also other, innovative applications such as offshore maintenance scheduling. As forecasts are directly used for decision-making (be it by a human or a machine), and bad decisions can lead to potentially large financial losses, "forecasting" has to provide a full view on how much power will be generated: being only provided with point-estimates is not desirable for a decision-maker as it does not inform about model uncertainty and hence allow a proper quantification of risk.

Existing commercial solutions typically create forecasts for a site from a physical (i.e., meteorological) model, correct it by some black-box

statistical method (e.g., a neural network), and add "uncertainty" by some ad-hoc scheme—and often more as an afterthought.

To address these shortcomings, we develop a new approach based on a fully probabilistic model which connects pieces of information in a more transparent way and produces posterior distributions coming naturally from the model itself.

We consider the scenario where we want to forecast a single site over a horizon of up to 16 hours ahead. The target quantity, power produced, is formulated as a time-series object in a Bayesian state-space setting with exogenous information, where the underlying unobservable weather dynamics is modeled by a non-linear, non-parametric Gaussian process (e.g., [Frigola, 2015]). Inferring the posterior distribution is done via PGAS, a particle-based MCMC procedure. To perform inference, we consider variational (cf. [Frigola et al., 2014]) and reduced-rank (cf. [Svensson et al., 2016]) approximation.

#### 3 - Forecasting supplies and demands in gas networks

*Inken Gamrath*

Forecasting demands and supplies in networks is very important for network related planning problems. When knowing what might happen, the network can be controlled by planning arrangements which can't be enforced immediately. For instance, hardware in a telecommunication network could be shut down and switched on when needed, which takes some time to be performed, or telecommunication traffic could be routed in advance. In gas networks, one can plan how the components (valves, control valves, compressors, etc.) should operate to adjust the gas distribution in the network; good forecasts are important since the gas needs some time to flow through the network.

Using the example of gas networks, we present short term forecasting of in- and outflows of the network. Therefore, we introduce an optimization based approach to forecast the demands and supplies and compare it to other approaches. We show results for data of the biggest German transmission system operator of gas networks. Furthermore, we will point out the advantage of using optimization in the field of forecasting.

## ■ WC-14

Wednesday, 13:30-15:00 - RVH|II

### Analytics in Retail and Digital Commerce I

Stream: Business Analytics, Artificial Intelligence and Forecasting

*Parallel session*

Chair: *Thomas Setzer*

#### 1 - Potential Benefits of User Rankings for Predictions of Booksellings

*Nicole Reuss, Klaus Ambrosi*

In Germany, the publication of new books is traditionally announced in spring and in autumn. Booksellers have to decide which books they want to order in which quantities up to six month before release. To ease the decision process, publishers usually send catalogues comprising information about the new releases as well as advance reading copies (ARCs) for some selected books. In addition, some catalogues might contain information about planned marketing actions. Apart from this, the booksellers need a lot of experience to calculate the right order quantities. While for popular authors the booksellers can use historical purchasing data to estimate the demand, it can be difficult to predict the success of new authors due to a lack of evidence. Consumers tend to read reviews before they decide on buying a certain book. Today, this process of opinion making is often shaped by the impact of social media and other web platforms. For example, reviews can be found on websites of online shops, blogs, and book communities, and this content is also frequently created by the consumers themselves. Sometimes, such reviews are published prior to the official book release. Given this trend, the objective of our study is to answer the following research questions: 1) Do ratings in book communities have any impact on the ranking of a certain book? 2) Is there a correlation between the rankings in book communities and the official bestseller lists? 3) Can online book reviews be used to predict the success or ranking of certain books that are not yet released? To address these research questions, an analysis of given data in web 2.0 platforms will be performed and different data mining techniques will be used to find patterns and correlations.

## 2 - Customer segmentation and market based analysis for an electronics retailer using machine learning and optimisation methods

*Hlynur Stefánsson, Júlíus Pétur Guðjohnsen, Sigurður Jónsson, Eyjolfur Asgeirsson*

In this contribution, we work with data from an electronics retailer and use machine learning and optimisation methods to gain actionable insights. We present a method for customer segmentation using self-organising maps (SOM). The SOM algorithm maps a high dimensional input space (customer features) onto a low dimensional output space (2D map) using unsupervised competitive learning. The results provide insights into customer behaviour and can be used to improve customer service and marketing strategies. Furthermore, the results from the customer segmentation are used as input for mining for products with high cross-selling potential within each customer segment. Those results are used by an optimisation model to determine the optimal product selection in promotions. Identifying and promoting products with high cross-selling potential for specific customer segments can aid in increasing the average basket size of the retailer resulting in increased revenues. Taking cross-selling effects into account is essential when it comes to replenishment decisions and category-management decisions, such as promotions, discontinuing or expanding certain categories within the retailer as it gives a deeper insight into the interaction between categories and how they affect sales.

## 3 - Efficiency Analysis of Migros Retail Stores in Turkey Using Data Envelopment Analysis

*Biröl Yüceoglu, Işıl Öztürk, Murat Çelebi*

Data envelopment analysis (DEA) is frequently used in order to assess the performance of decision making units. In this study, we use DEA to analyze the efficiency of stores belonging to Migros Turkey, a leading fast-moving consumer goods retailer in Turkey. We consider more than 1000 stores that are grouped under four formats with different size and product assortment and analyze each store format independently. After employing exploratory data analysis in order to determine outlying stores, we answer two questions related to store efficiency. First, we use output-oriented DEA in order to determine efficient stores and stores that need to perform better. The use of output-oriented DEA allows us to determine best practices for inefficient stores by setting new performance targets for a given input level. In other words, we try to increase the performance of stores by keeping inputs as constant as changing inputs in the short run is not easy. Second, we use input-oriented DEA in order to determine optimal characteristics of future stores. The use of input-oriented DEA allows us to determine optimal store characteristics based on the performance of existing stores.

and the discontinuous Galerkin approximation. Numerical experiment is performed for the traffic assignment problems, and the numerical results are reported for supporting our theoretical arguments and illustrating the good numerical performance of the proposed method.

## 2 - Hybrid Agent-Based Modeling (HABM) - A Formalism for Combining Agent-Based Modeling and Simulation, Discrete Event Simulation, and System Dynamics

*Joachim Block*

There is a growing interest within the operations research (OR) community in mixing different methods to form new kinds of optimization algorithms. Such hybrid algorithms offer a promising way for addressing real world problems that cannot be sufficiently solved by using single method approaches.

Very similar, some scholars argue that hybrid simulation could be a mean to support the decision making process for hard management problems. Hard problems are to a great extent dominated by intuition or judgement and hybrid simulation could contribute to more realistic models and, hence, result in better decisions. Despite considerable recent advances in coupling different modeling paradigms such as agents-based modeling and simulation, discrete event simulation (DES), and system dynamics (SD) research on hybrid modeling seems still to be in its infancy.

We present a modeling formalism intended to specify hybrid agent-based models (HABM) with elements from DES and SD. Basic idea is that agents not only exhibit discrete but also continuous behavior. Furthermore, the formalism has the capability to consider dynamic structures. Structural dynamics such as changing relations between agents as time passes by are an important property of agent-based models. The modeling formalism is founded on and extends the well established Discrete Event System Specification (DEVS).

We have used the formalism to support the decision making process in a strategic workforce planning context. However, HABM can also be applied to other OR fields such as supply chain networks simulation or even for the specification of agent-based meta-heuristic.

## 3 - Regulating the degree of conservatism: An error flexible single step approach to multiple testing

*Christina Bartenschlager, Jens Brunner*

Multiple testing concepts for testing more than one null hypothesis based upon the same data set become more and more sophisticated and at the same time users become more and more deterred. For instance, when deciding on at least 55 multiple testing procedures the user at first has to decide on eight multiple  $\alpha$ -error definitions, which guarantee different degrees of conservatism regarding the rejection of null hypotheses. This situation results in neglecting multiple testing in empirical research and thus an imperilment of the reliability of research findings:  $\alpha$ -errors can inflate significantly with the number of tested null hypotheses by employing a series of conventional tests. We present a new application-oriented multiple method that is able to outline different multiple  $\alpha$ -error definitions at the same time by mixing the intuitive multiple Bonferroni correction and well-known conventional tests. Simulation studies show that this results in a significantly better performance than existing comparable procedures. Thus, our new method transforms the two-stage decision on multiple  $\alpha$ -error definitions and multiple tests to a one-stage decision on the multiple  $\alpha$ -error definition. In addition, our method is the first one that is able to control the False Discovery Rate, i.e. one multiple  $\alpha$ -error definition, by a single step concept.

## ■ WC-15

*Wednesday, 13:30-15:00 - RVH|III*

### Advances in Modelling and Simulation Methodologies

Stream: Simulation and Statistical Modelling

*Parallel session*

Chair: *Zhengyu Wang*

#### 1 - Galerkin Method for Dynamic Nash Equilibrium Problem with Shared Constraints

*Zhengyu Wang, Stefan Wolfgang Pickl*

The dynamic Nash equilibrium problem with shared constraints involves a decision process with multiple players, where each player solves an optimal control problem with his own cost function and strategy set, both dependent on the rivals' control variables. Such a problem appears frequently in realistic applications like in traffic assignment with side constraints, the numerical solution for this problem is challenging and has attracted growing attention in Operations Research community.

In this talk we introduce a variational inequality reformulation of this dynamic Nash equilibrium problem, which presents the dynamic and the equilibrium nature of the problem in a systematic way. This reformulation is advantageous since the variational inequality has been intensively studied and abundant theory is available. In addition, we propose a new numerical method by combining the exponential integrator

## ■ WC-16

*Wednesday, 13:30-15:00 - RBM|1102*

### Finance II

Stream: Finance

*Parallel session*

Chair: *Michael H. Breitner*

#### 1 - A Generalization for the Duration concepts

*Marius Radermacher*

Duration concepts are standard methods for measuring interest rate risks of portfolios. Macaulay duration, effective duration and Key-Rate duration are mostly used according to different types of yield curves. In this lecture, a generalization of the duration concept is presented, by using multi-dimensional Taylor series development. It allows to measure the interest rate risk based on variable yield curves (variable forward rates). They even can be negative. The standard duration concepts turn out to be special cases within this approach. For actuarial purposes, it also allows to measure the mortality risk.

## 2 - Enhancing the wisdom of the crowd - evidence from social trading

*Christopher Helm, Martin Rohleder*

We propose a novel crowd aggregation approach, which considers the past returns and experience of crowd members, while maintaining the diversity of opinions provided by all members of the crowd. We test our "crowd ensemble" alongside alternative crowd approaches on a unique and comprehensive dataset of 12,144 social trading portfolios. These "wikifolios" publish all of their individual trading decisions on the platform wikifolio.com. The data covers over 2.5 million trades between 2012 and 2015. From such trades, we derive daily portfolio holdings and use the resulting portfolio weights as asset allocation signals, weighted based on the wikifolio's past return, which also serves as a proxy of traders' experience and learning progression. Our results indicate that compared to a market cap weighted market portfolio, crowd aggregations provide superior risk adjusted returns according to the Carhart (1997) model. However, a detailed risk factor loadings analysis additionally shows that alternative crowds suffer from behavioral biases. Young and unexperienced wikifolios are generally less diversified and place a higher weight on small stocks. We hypothesize that newly created wikifolios try to stand out from their counterparts and provide a unique, recognizable profile to attract followers, similar to the phenomenon of "mutual fund incubation". Conversely, the crowd ensemble does not display any remarkable factor loadings on any risk factors except the market. Overall, our results provide valuable new insights into the behavior of individual investors. Moreover, the crowd ensemble is not restricted to stock portfolio decisions or finance in general but may be applied to many other non-mutually exclusive decisions between alternatives.

## 3 - Improving the recovery rate of unsecured debt in multistep workout processes

*Johannes Kriebel, Kevin Yam*

Forecasting recovery rates is usually mainly concerned with the prediction of a customer's capacity to repay defaulted debt given a set of contract, demographic and macroeconomic information. In this paper, we suggest a model to determine workout strategies given the stylized fact that debtors react differently to weaker and stronger workout actions (e.g. mail contact, phone contact, legal proceedings). Debtors are *ceteris paribus* more likely to pay when faced with stronger workout actions but stronger workout actions tend to be more costly for the creditor. There is therefore a need to find optimal workout strategies for the creditor. We suggest a regression model in which the creditworthiness of a debtor is a linear combination of debtor characteristics. The reaction towards workout actions is incorporated by using skewed error terms that make payments more likely for strong workout measures and less likely for weak workout measures. We outline, how the model coefficients and skewness parameters can be estimated from empirical data. Using simulated data, we show that model predictions can be substantially improved using our model to account for the debtor's behaviour when compared to predictions from a logistic regression model. We further show that the workout success in terms of the sum of net payments can be improved substantially by using the suggested model to choose appropriate workout actions when compared with other alternative ways to determine the workout strategy.

## 1 - Duty Rostering for Physicians at a Department of Orthopedics and Trauma Surgery

*Clemens Thielen*

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. Creating duty rosters for physicians is particularly challenging due to complex constraints (resulting, e.g., from minimum rest times and physician preferences) that should be satisfied by a "good" roster. In larger departments, these constraints cannot be handled adequately when generating duty rosters manually. This motivates using mathematical optimization models in order to generate duty rosters for physicians that satisfy all arising constraints and at the same time allow an efficient operation of the department.

We present an integer programming model for the generation of duty rosters for physicians at a large department of orthopedics and trauma surgery that is used in practice since January 2016. Besides the specific constraints that need to be respected and the resulting model, we additionally present ways of dealing with unpredictable disruptions (caused, e.g., by absence of physicians due to illness) and evaluate the generated duty rosters from a practical perspective.

## 2 - Robust Cyclic Apprenticeship Scheduling with an Application in Resident Scheduling

*Sebastian Kraul, Jens Brunner*

The complexity of apprenticeships is rising in highly technological industries. As a consequence, traineeships are not only time-related but task-related. In an apprenticeship, trainees have to pass several departments of a company in a specific time. Predicting the exact number of procedures that a trainee can perform in these periods is not always possible. Accordingly, a trainee might not be able to perform all of the needed procedures resulting in an extension of the apprenticeship. Beside this reliability problem there is often a shortage of trainees so that organizations are faced with new challenges. On the one hand, they have to make efforts to get the best candidates for their programs. On the other hand, they need to stay cost-efficient concerning their personnel planning. A good quality, systematic and scope of trainee programs is a possible opportunity to respect both sides. A cyclic model is presented that is able to generate robust syllabi individually for each trainee and also to estimate the optimal number of trainees in the system. In addition to that, the model solution gives an employment policy for the organization. Since the compact formulation is not able to find solutions fast, a Dantzig-Wolfe-Decomposition is used to accelerate the solution process. A pattern generation approach that is able to construct multiple patterns out of one solution is exposed for cyclic problems. The termination of column generation can be accelerated significantly by this approach. The model is evaluated by a real world case of a resident program in a German hospital and tested in a computational study with different parameter settings. The results can be used to ensure service quality even in case of departmental change of the trainees.

## 3 - A Column Generation Approach to Flexible Nurse Scheduling

*Jan Schoenfelder, Markus Seizinger*

We model a hospital's scheduling decisions for (partially) cross-trained nurses under uncertain demand. While we approximate the true demand distribution by formulating a deterministic equivalent formulation, we are able to incorporate a refined set of possible demand realizations by employing a column generation approach. Based on data collected from three hospitals, we derive insights into the potential benefit that may or may not be gained from employing cross-trained nurses. Furthermore, we analyze the schedule improvements that result from incorporating possible nurse reassignments into the initial scheduling decisions.

## ■ WC-17

Wednesday, 13:30-15:00 - RBM|2204

### Staff Scheduling

Stream: Health Care Management  
*Parallel session*

Chair: *Jens Brunner*

## ■ WC-18

Wednesday, 13:30-15:00 - RBM|2215

### Scheduling on Parallel Machines

Stream: Project Management and Scheduling  
*Parallel session*

Chair: *Marcin Zurowski*

### 1 - Runway Scheduling under Consideration of Winter Operations

Maximilian Pohl, Rainer Kolisch

We address the problem of scheduling incoming and departing aircraft on multiple runways under consideration of snow removal and runway de-icing during winter operations. Since this problem has not been addressed so far in the literature, we are presenting a mixed-inter program (MIP) with the objective of minimizing the weighted earliness and lateness of scheduled starting and landing times. We report about solving small to medium real-world instances from Franz Josef Strauß airport in Munich. Since larger instances cannot be solved to optimality, we will also be discussing heuristic approaches.

### 2 - Explicit modelling of multiple intervals in a constraint generation procedure for multiprocessor scheduling

Emil Karlsson, Elna Rönnerberg

Multiprocessor scheduling is a well studied NP-hard optimisation problem that is of interest in a variety of applications. The focus of this paper is explicit modelling of tasks with multiple intervals. This work extends a constraint generation procedure previously developed for avionics scheduling and we here address a relaxation of the problem that can be considered as a multiprocessor scheduling problem with dependencies and chains. A dependency restricts the time from one task instance to another and a chain prescribes that task instances execute in a specified order.

The explicit modelling of tasks with multiple intervals facilitates the introduction of valid inequalities to strengthen the model formulation used in the constraint generation procedure. We illustrate the computational effects of the formulation on instances that are relevant in an avionics context since these instances lend themselves to such a formulation.

### 3 - Scheduling jobs and maintenance activities subject to job-dependent machine deteriorations

Liliana Grigoriu, Dirk Briskorn

We consider machine scheduling that integrates machine deterioration caused by jobs by also scheduling maintenance activities. The maintenance state of the machine is represented by a maintenance level which drops by a certain, possibly job-dependent, amount while jobs are processed. A maintenance level of less than zero is associated with the machine's breakdown and is therefore forbidden. Hence, maintenance activities that raise the maintenance level may become necessary and have to be scheduled additionally. We consider the objective to minimize the makespan throughout the paper. For the single machine case, we provide a linear-time approximation algorithm with worst-case a bound of  $5/4$ , and comment on how an FPTAS from previous literature can be employed to apply to our problem. Due to problem similarity, these results also apply to the minimum subset sum problem, and the  $5/4$  linear-time approximation algorithm is an improvement over the  $5/4$  quadratic-time approximation algorithm of Güntzer and Jungnickel. For the general problem with multiple machines, we provide approximability results, two fast heuristics, an approximation algorithm with an instance-dependent approximation factor, and a computational study evaluating the heuristics. For integers  $k$  that are greater than 5 we present  $(k+1)/k$  linear-time approximation algorithms for minimum subset sum (assuming that  $k$  is constant) that were developed using the ideas that led to the  $5/4$  approximation algorithm.

### 4 - Preemptive scheduling of jobs with a learning effect on two parallel machines

Marcin Zurowski

Scheduling problems with variable job processing times occur very often in practice. For example, the variable processing times of jobs may depend on the starting times or positions of the jobs in schedule. One of the more popular models of variable job processing times is the model of scheduling jobs with a learning effect. In this model, the variable processing time of each job is the product of the job basic processing time and the value of a non-increasing function of the job position in schedule. The range of applications of the model, however, is limited by the fact that one assumes that jobs are non-preemptable. In the presentation, we consider a problem of preemptive scheduling of jobs with a learning effect. In the problem, a set of independent and preemptable jobs has to be scheduled on two parallel identical machines. The optimality criterion is the maximum completion time. We show by examples that applying the definition of preemptability known in the classical scheduling theory leads to some anomalies. Based on analysis of these examples, we introduce a new definition of job preemptability. Finally, we prove some properties of our problem and propose an exact algorithm for finding an optimal schedule.

## ■ WC-19

Wednesday, 13:30-15:00 - RBM|3302

### Production and Service Networks II

Stream: Production and Operations Management

Parallel session

Chair: Foad Ghadimi

#### 1 - Overtime planning and safety stock placement in production networks

Tarik Aouam

Efficiently matching supply and demand in capacitated production networks while considering variability is the challenge we address in this work. We consider a supply network facing uncertain demand, where each facility is a series of raw material inventory, a capacitated workstation and finished goods inventory. Safety stocks can be carried at various stages to hedge against demand uncertainty. The safety stock placement problem, following the guaranteed service approach, determines the location and quantity of safety stocks, when stages quote guaranteed service times. Safety stocks depend on the quoted service times between stages and the production cycle time (PCT) of each stage. Each stage can use overtime to increase production capacity and mitigate PCT variability. We formulate, analyze, and solve the problem of jointly optimizing overtime planning and safety stock placement with the objective of minimizing production and inventory costs while satisfying a target service level. Extensive numerical experiments show the efficiency of the proposed solution procedure and characterize the effect of various parameters on basic trade-offs between production and inventory costs.

## ■ WC-20

Wednesday, 13:30-15:00 - RBM|4403

### Supply Chain Inventories

Stream: Supply Chain Management

Parallel session

Chair: Christopher Grob

#### 1 - Optimal Randomized Ordering Policies for a Capacitated Two-Echelon Distribution Inventory System

Taher Ahmadi

We propose a new formulation for controlling inventory in a two-echelon distribution system consisting of one warehouse and multiple non-identical retailers. In such a system, customer demand occurs at the retailers and propagates backward through the system. The warehouse and the retailers have a limited capacity for keeping inventory and if they are not able to fulfill the demand immediately, the demand will be lost. All the locations review their inventory periodically and replenish their inventory spontaneously based on a periodic randomized ordering (RO) policy. The RO policy determines order quantity of each location at each period by subtraction corresponding on-hand inventory at the beginning of that period from a deterministic decision variable. We propose a mathematical model to find the optimal RO policies such that an average systemwide cost consisting of ordering, holding, shortage, and surplus costs is minimized. We use the first and second moment of on-hand inventory as auxiliary variables. A remarkable advantage of our model is to calculate the immediate fill rate of all locations without adding new variables and facing the curse of dimensionality. Using two numerical examples with stationary and non-stationary demand settings, we validate and evaluate the proposed model. For the validation, we simulate the optimal RO policy and demonstrate that the optimal first and second moments of on-hand inventory from our model reasonably follow the corresponding moments obtained through simulation. Furthermore, we evaluate the RO policy by drawing a comparison between the optimal RO policy and the optimal well-known (R, s, S) policy. The results confirm that the RO policy could outperform (R, s, S) policy in terms of the average systemwide annual cost.

## 2 - Window Fill Rate with Compound Arrival and Assembly Time

Michael Dreyfuss

Exchangeable-item repair systems are inventory systems in which customers receive operable items in exchange of the failed items they brought. The failed items are not discarded, but instead, they are repaired on site. We consider such a system in which failed item arrival follows a Compound Poisson process and in which assembly and disassembly times of the items is nonzero. For this system we develop exact formulas for the window fill rate, that is, the probability that customers receive service within a specific time window. This service measure is appropriate in situations that customers tolerate a certain delay and therefore the system does not incur reputations costs if it completes service within this time window.

## 3 - A solution procedure for joint optimization of reorder points in n-level distribution networks using (R,Q) order policies

Christopher Grob, Andreas Bley, Konrad Schade

We present an algorithm to minimize the investment in stock in a n-level inventory distribution network with stochastic demands and wait times using a (R,Q) policy. Our research is motivated by the inventory planning for a worldwide spare parts supply chain of a big automotive company. The algorithm is fast enough to be used in real world applications. It is, to our knowledge, the first one to determine reorder points for inventory distribution systems using complex wait time approximations. In a previous work, we determined optimal reorder points for a 2-level network, which cannot easily be extended to n-levels. The service constraints included in these models are nonlinear and can be evaluated only using a time-consuming binary search. Our work uses the wait time approximations by Kiesmüller et al. Service constraints only apply at local warehouses, i.e., the last level of the network where customer demand is fulfilled. To cope with these challenges, we underestimate the original non-linear constraints by piecewise linear functions by strictly overestimating the effect of a stocking decision at non-local warehouses on local-warehouses and we create constraints that trade-off stocking decision between all non-local warehouses. We iteratively solve the resulting integer program and refine the piecewise linear functions adaptively during the execution of the algorithm. In each iteration we are able to evaluate the quality of the solution and can terminate the algorithm when the optimality gap is as small as required.

different load cases (turn pumps on or off). Since the characteristic curves of the pumps in the construction kit are nonlinear, this leads to a Mixed Integer Nonlinear Program (MINLP). We model the MINLP in the framework JuMP and solve it with SCIP. We show the best layout option and operation strategy found by our approach and compare the energy savings with a conventional system design.

## 2 - Product Family Design Optimization using Model Based Engineering Techniques

David Stenger, Tankred Mueller, Lena Charlotte Altherr, Peter Pelz

Highly competitive markets paired with great production volumes demand particularly cost efficient products. The usage of common parts and modules across product platforms can potentially reduce production costs through economy of scale. Yet, increasing commonality may result in overdesign of individual products. Thus, product families as a whole instead of individual products need to be optimized for minimal overall costs. Multi domain virtual prototyping enables designers to evaluate cost and technical feasibility of different single product designs at reasonable computational effort in early design phases. However, multidimensional parameter spaces combined with product families consisting of many products make the optimization of the whole product family a challenging task. Additionally, savings by platform commonality are hard to quantify and require detailed knowledge of the production process and the supply chain. Therefore, we present a multi-objective metamodeling-based optimization algorithm which enables designers to explore the trade-off between platform commonality and cost optimal design of the single products in an industrial setting. The method is demonstrated on a mechatronic drive system product family.

## 3 - How Do Structural Designs Affect the Economic Viability of Offshore Wind Turbines? An Interdisciplinary Simulation Approach

Clemens Huebler, Jan-Hendrik Piel, Raimund Rolfes, Michael H. Breitner

Offshore wind energy is a seminal technology to achieve the goals set for the deployment of renewable energies. However, offshore wind energy projects are today not yet sufficiently competitive to be realized without financial support mechanisms. Consequently, the optimization of offshore wind turbine substructures with regard to costs and reliability is a promising approach to increase cost-efficiency and competitiveness. Interdisciplinary optimization concepts considering sophisticated engineering models and their complex economic effects are rare and, in general, deterministic. We address this research gap by combining an aero-elastic wind turbine model, being capable to estimate costs and stochastic lifetimes of substructure designs, with an economic viability model for Value-at-Risk analyses of investments in offshore wind energy projects. By means of our modelling approach, we investigate the impact of three slightly different substructure designs on the profitability and financial viability of a simulated offshore wind energy project. We differentiate the substructures with regard to diameters and wall thicknesses of legs and braces and create a classical, a conservative, and a risky design. For each substructure, our aero-elastic wind turbine model yields an own fatigue lifetime distribution and different total costs due to changing masses, welding and coating costs, which we then apply in our economic viability model. Our results indicate that the effect of the initial cost differences slightly exceeds the effect of the differences in the stochastic lifetime on the competitiveness of the simulated project.

## ■ WC-21

Wednesday, 13:30-15:00 - RBM|4404

## Optimization of Technical Systems

Stream: OR in Engineering

Parallel session

Chair: Lena Charlotte Altherr

### 1 - Energy efficient design of a decentralized fluid system by mixed integer nonlinear programming

Philipp Leise, Lena Charlotte Altherr, Peter Pelz

Energy efficiency of technical systems has become more and more important in recent times. Based on governmental energy efficiency regulations and environmental protection rules, the systematic design of technical systems is a key factor to improve the whole systems' efficiency. Once the components' interaction is taken into account, further potential for optimization opens up. An approach for the systematic design of technical systems was developed at the Chair of Fluid Systems at TU Darmstadt. With "Technical Operations Research" (TOR) it is possible to ensure a global optimal layout and operation strategy of technical systems. With this work, we show the practical usage of this approach for the systematic design of a decentralized water supply system for skyscrapers. At the beginning, a construction kit of multiple key parts like pumps and pipes and the different load cases are chosen by the human designer. Afterwards the system is designed by a Mixed-Integer Nonlinear Program to support the human designer during the multiple layout decisions. To model all possible network options of the water supply system in skyscrapers, tree structured graphs are used. Binary variables are introduced to model the selection of different components at different levels in the building. Additional binary variables are introduced to model the operation strategy in the

## ■ WC-22

Wednesday, 13:30-15:00 - HFB|A

## MCDM 1: Complexity and Special Techniques

Stream: Decision Theory and Multiple Criteria Decision Making

Parallel session

Chair: Kathrin Klamroth



## 1 - The Multiobjective Shortest Path Problem is NP-hard, or is it?

Fritz Bökler

To show that multiobjective optimization problems like the multiobjective shortest path or assignment problems are hard, we often use the theory of NP-hardness. In this talk we rigorously investigate the complexity status of some well-known multiobjective optimization problems and ask the question if these problems really are NP-hard. It turns out, that most of them do not seem to be and for one we prove that if it is NP-hard then this would imply  $P = NP$  under assumptions from the literature. We also reason why NP-hardness might not be well suited for investigating the complexity status of intractable multiobjective optimization problems.

## 2 - Optimization of Bi-Objective TSP

Thomas Stidsen, Kim Allan Andersen, Kim Allan Andersen

A large number of the real world planning problems which are today solved using Operations Research methods are actually multiobjective planning problems, but most of them are solved using single-objective methods. The reason for converting, i.e. simplifying, multiobjective problems to single-objective problems is that no standard multi-objective solvers exist and specialized algorithms needs to be programmed from scratch. Over the last decades two different approaches to solve, to optimality, Multi-Objective Mixed Integer Programming (MOMIP) models has emerged: Criterion space approaches and decision space approaches. Criterion space approaches iteratively solves a number of single-objective MIP's. Decision space approaches extend the classic Branch & Bound algorithm to handle more than one objective

In this article we will present a hybrid approach, which both operate in decision space and in objective space. The classic Branch & Bound algorithm is extended to handle two objectives, i.e. specialized bounding and branching methods are utilized. Furthermore a criterion-space based parallelization is performed, enabling simple massive parallelization, since no communication between the processes is necessary. This Branch & Bound (Cut) approach can be used for a wide variety of bi-objective Mixed Integer Programming models. We test the approach on the biobjective extension of the classic traveling salesman problem, on the standard dataset, and determine for the full set of nondominated points for 100 city problems. The found exact Pareto fronts have a size between 1900 and 3300 points, i.e. tours.

## 3 - Multiobjective optimization for complex systems

Kathrin Klamroth, Stefan Ruzika, Margaret Wiecek

We consider complex systems that are composed of two subsystems with single or multiple objectives. Their complexity is reflected, among others, in the fact that direct solution approaches are available only at the subproblem level and not at the level of the entire system. In practical applications, these subsystems model, for example, different parts or aspects of an overall system. Such subsystems often have interactions with each other and they are usually not sequentially ordered or obviously decomposable. Thus, the individual solutions of subsystems do not generally induce a solution for the overall system. We discuss subsystem and system feasibility and suggest different notions of optimality for complex systems with two interacting subsystems. Solution concepts are discussed in the light of recent developments in this field.

## ■ WC-23

Wednesday, 13:30-15:00 - HFB|B

### Game Theory and Optimization

Stream: Game Theory and Experimental Economics  
Parallel session

Chair: Mark Francis Rogers

## 1 - An Efficient and Truthful Algorithm for Fair Scheduling on Related Machines

Ruini Qu, Bo Chen

With rapid expansion of traditional scheduling models to multi-agent systems, soliciting true system information owned privately by individual agents is fundamental in scheduling for system optimality. In this study, we are concerned with allocating a set of independent jobs to a number of related machines that are owned by self-interested agents in

such a way that the allocation is as fair as possible (in terms of minimizing some Chebyshev distance to a virtually fairest allocation). The related machines differ only in their processing speeds, which are private information of the individual agents who own the machines and hence subject to misreports. Our challenge is to establish an allocation mechanism that is of high quality on all three objectives: (a) efficiency in allocating jobs, (b) truthfulness in soliciting private information of speeds and (c) optimality in achieving fairness.

As a touchstone for the design of efficient algorithms for scheduling parallel machines, LPT (the largest-processing-time-first) heuristic has been attracting research attention since late 1960s. In this talk, we show that a modified LPT algorithm proposed in the literature is of high quality in fairness (c) in addition to its already recognized efficiency (a) and truthfulness (b).

## 2 - How Additional Exit Affect the European Union's Power Distribution

Mark Francis Rogers, Dóra Gréta Petróczy, László Kóczy

After Brexit debates on an own EU-leaving referendum arose in the Czech Republic and the Netherlands too. In this paper, firstly we analyse the possible impacts of the Czech Republic's exit from the EU. Then we observe how the exit of any member state from the union would affect the power distribution of the member states within the EU. From the impacts of a possible leaving we inspect one factor: how the power distribution changes in the Council of the European Union. Because the Treaty of Lisbon specified the decision-making to the number of members and the population, an exit of a member state does not invoke the renegotiation of the voting weight system. Using the Shapley-Shubik power index, we calculated the power of the member states both with and without the member who might leave the union. Because the actual budget changes in case a member state leaves the union, we adjusted the new power indexes with the change in the budget caused by the leaving of the member state. We found a pattern connected to a change of the threshold of the required member states and the change in power distribution. An exit which causes a change to the member state threshold of the Council of the European Union benefits large, an exit which does not cause such a change benefits small member states.

## ■ WC-24

Wednesday, 13:30-15:00 - HFB|C

### GOR Master Thesis Prize

Stream: Awards

Parallel session

Chair: Stefan Ruzika

## 1 - Stable Clusterings and the Cones of Outer Normals

Felix Happach

We consider polytopes that arise in the cluster analysis of a finite set of data points. These polytopes encode all possible clusterings and their vertices correspond to clusterings that admit a power diagram, which is a polyhedral separation of the underlying space in which each cluster has its own cell. We study the edges of these polytopes and show that they encode cyclical transfers of elements between clusters. We use this characterization to obtain a relation between power diagrams and the volume of the cones of outer normals of the respective clustering. This allows us to derive a new stability criterion for clusterings, which can be used to measure the dependability of the clustering for decision-making. Further, the results explain why many popular clustering algorithms work so well in practice.

## 2 - Solving the Time-Dependent Shortest Path Problem on Airway Networks Using Super-Optimal Wind

Adam Schienle

We study the Horizontal Flight Trajectory Optimisation Problem (HFTOP), where one has to find a cost-minimal aircraft trajectory between airports  $s, t$  on the Airway Network, a directed graph. We distinguish three cases: a static one where no wind is blowing, and two cases where we regard wind as a function of time. This allows us to model HFTOP as a Shortest Path Problem in the first case and a Time-Dependent Shortest Path Problem in the latter cases.

In the static case, we compare the runtimes of Dijkstra's algorithm to those of  $A^*$  and Contraction Hierarchies (CHs). We show that  $A^*$  guided by a great-circle-distance potential yields speedups competitive to those of CHs.

In the time-dependent version, we study two different modelling approaches. Firstly, we compute the exact costs for the time on the arcs. In a second version, we use piecewise linear functions as the travel time. For both versions, we design problem-specific potential functions for the A\* algorithm. As the exact costs are non-linear, we introduce the notion of Super-Optimal Wind to underestimate the travel time on the arcs, and show that Super-Optimal Wind yields a good underestimation in theory and an excellent approximation in practice. Moreover, we compare the runtimes of the time dependent versions of Dijkstra's Algorithm, A\* and Time-dependent Contraction Hierarchies (TCHs) in the PWL case, showing that A\* outperforms Dijkstra's Algorithm by a factor of 25 and TCHs by a factor of more than 16.

For the exact case, we compare Dijkstra's Algorithm to A\* and show that using Super-Optimal Wind to guide the search leads to an average speedup of 20.

### 3 - The two dimensional bin packing problem with side constraints

Markus Seizinger

We propose a new variant of Bin Packing Problem, where rectangular items of different types need to be placed on a two-dimensional surface. This new problem type is denoted as two-dimensional Bin Packing with side constraints. Each bin may consist of different two-dimensional layers, and items of different types may not overlap on different layers of the same bin. By different parameter settings, our model may be reduced to either a two- or three-dimensional Bin Packing Problem. We propose practical applications of this problem in production and logistics. We further introduce lower bounds, and heuristics for upper bounds. We can demonstrate for a variety of instance classes proposed in literature that the GAP between those bounds is rather low. Additionally, we introduce a Column-Generation based algorithm that is able to further improve the lower bounds and comes up with good solutions. For a total of 400 instances, extended from previous literature, the final relative gap was just 6.8%.

## ■ WC-25

Wednesday, 13:30-15:00 - HFB|D

### Gas Networks and Market

Stream: Energy and Environment  
Parallel session

Chair: Dominik Möst  
Chair: Philipp Hauser

#### 1 - Benefits and Limitations of Simplified Transient Gas Flow Formulations

Felix Hennings, Tom Streubel

The mathematics of gas transportation networks have been much studied in recent years. However, the optimization of the time-dependent transient control of large real world networks is still out of reach for current state-of-the-art approaches. Due to this, we investigate further simplifications of the model constraints describing the gas network elements. We aim at significantly reducing the problem complexity while preserving a good approximation of the more complex element behavior.

#### 2 - The Value of Diversified Infrastructure in the European Natural Gas Market Using Chance Constrained Programming

Philipp Hauser

The ongoing transformation of the energy system in Germany and Europe aims to reduce CO<sub>2</sub>-emissions. Against this background, the role of gas in the energy mix and the need of investment in gas infrastructure in the next decades is unclear. In gas markets, uncertainties occur in three 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. Secondly, uncertainties raise on the supply side, where decreasing European gas production in western Europe enhance the market position of non-European suppliers as Russia or Qatar and simultaneously increase the European dependence on supplies of these countries. Finally, 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. According to these challenges the paper will focus on uncertainties on the supply and transmission side. As the overall goal of energy policy is to ensure security of supply, the question of diversification in both, gas suppliers and transmission ways, gains in importance. Therefore, the objective is to calculate the value of diversified infrastructures using an extended version of the linear optimization model Gas market model (GAMAMOD). An application of the chance constrained programming approach will be introduced in order to evaluate total system costs of different infrastructure scenarios by taken uncertainties of supply interruptions into account.

## ■ WC-26

Wednesday, 13:30-15:00 - HFB|Senat

### Automated Negotiations in Logistics (i)

Stream: Game Theory and Experimental Economics  
Parallel session

Chair: Tobias Buer

#### 1 - Improving a Genetic Algorithm-based Mechanism for Allocating Requests in Transport Coalitions

Jonathan Jacob, Tobias Buer

The allocation of transportation requests in coalitions of freight carriers is an area of growing interest. The main challenge in that field of research is to reconcile the conflicting goals of maximizing the coalition's profits, restricting information shared between the carriers, and allocating surplus profits. We examine a number of improvements to an existing mechanism for solving the transportation request assignment problem (TRAP), where a pool of pickup-and-delivery requests with profits gets partitioned between the members of a transport coalition. In this mechanism, request allocations are encoded as arrays of integer numbers which are used as chromosomes of a genetic algorithm (GA). The members of the coalition place bids on each chromosome, the sum of which is used as the fitness function of the GA. This way, as opposed to most existing approaches, no direct information about the carriers' valuations of single requests or routes is disclosed to the coalition. The surplus profit generated is distributed evenly between the carriers. The improvements to our mechanism for solving the TRAP we examine comprise the introduction of a geographical component into the set-up of the initial population of the GA, as well as the analysis of different selection, crossover, and mutation operators. We run tests of our mechanism with different parameter settings regarding these improvements and compare their results with each other and the results obtained through centralized planning.

#### 2 - A combinatorial double auction for exchanging empty marine containers

Tobias Buer

For many regions in the world, the volume of imported and exported goods is imbalanced. Consequently, in seaborne trade the supply and demand of empty containers is imbalanced, too. This creates the need for repositioning of empty containers. The costs of repositioning empty containers could be reduced if the involved ocean carriers would or could cooperate more intensively. However, in many situations sharing the necessary data among competing carriers is not an option due to privacy concerns. Therefore, in order to balance supply and demand of empty containers we propose an exchange mechanism based on a double auction. Market players may be all organisations which supply or demand empty containers, in particular (but not limited to) carriers. In the proposed auction, the bidders buy and sell the right to use a number of empty containers at a specific location on a certain day defined by their bids. A bidder may combine multiple individual bids into a bundle bid. Bundle bidding avoids the exposure problem. By means of bundle bidding, a bidder is able to construct a transport network which is more balanced with respect to supply and demand of empty containers. In order to support the auctioneer of such a double auction we propose and study a model for the winner determination problem of a multi-period empty container exchange mechanism with bundle bidding. The impact of different objective functions on the clearing of the auction is studied by means of computational experiments.

### 3 - Agent-driven versus mediator-driven contract proposal in automated negotiations

*Gabriel Franz Guckenbiehl, Tobias Buer*

Automated negotiation mechanisms (ANMs) are used to negotiate well-structured and complex contracts. Complex contracts are used, for example, to align suppliers in a supply chain. Negotiations among multiple agents easily get stuck in a local optimum because the agents block each others proposals. Many negotiation mechanism are mediator-driven, i.e., they assume a new contract proposal is generated by a neutral mediator. However, as the agents are not willing to disclose private information about their utility functions, the search process of the mediator is uninformed. Therefore, mediator-based ANMs usually use randomized contract proposal mechanisms. This preserves private information of the agents but may extend the negotiation process considerably.

A way to overcome this deficit may be to allow agents to propose their own contracts. As agents propose contracts, each new proposal benefits at least one agent. In contrast, in mediator-driven negotiations many contracts proposed by the (uninformed) mediator may not be improving at all. On the other hand, agent-driven negotiations may get stuck in local optima even faster and, therefore, result in inferior contracts. In these agent-driven negotiations the performance depends, among others, on the sequence in which the agents are allowed to propose new contracts. We study the impact of three different sequences (random, static, result-dependent) on the performance of four ANMs: greedy, greedy with compensation payments, simulated annealing, and simulated annealing with compensation payments. Based on computational results we provide insights on the performance of mediator-driven versus agent-driven automated negotiation mechanisms.

## Wednesday, 15:30-16:15

### ■ WD-01

*Wednesday, 15:30-16:15 - WGS|101*

#### Cancelled: Semi-Plenary Panos M. Pardalos

Stream: Semi-Plenaries  
*Semi-plenary session*

Chair: *Stefan Wolfgang Pickl*

### ■ WD-22

*Wednesday, 15:30-16:15 - HFB|A*

#### Presentation by the GOR Science Award Winner

Stream: Semi-Plenaries  
*Semi-plenary session*

Chair: *Karl Inderfurth*

#### 1 - Presentation by the GOR Science Award Winner (Name: to be announced!)

*Karl Inderfurth*

The GOR Science Award is the most prestigious prize awarded by the German OR society. In this semi-plenary session, this year's GOR Science Award winner will present an overview of his research. The winner will be announced at the conference opening plenary session.

### ■ WD-23

*Wednesday, 15:30-16:15 - HFB|B*

#### Semi-Plenary Dirk Christian Mattfeld

Stream: Semi-Plenaries  
*Semi-plenary session*

Chair: *Jan Fabian Ehmke*

#### 1 - Models and Optimization in Shared Mobility Systems

*Dirk Christian Mattfeld*

IT-based processes have fostered the rise of shared mobility business models in recent years. In order to play a major role in people's future transportation, reliable shared mobility services have to be ensured. The availability of a shared vehicle at the point in time and location of spontaneously arising customer demand is recognized as requirement to replace individual vehicle ownership in the long term. Methodological support for shared mobility systems can draw on operations research models originally developed in the field of logistics. We give an overview on optimization models with regard to network design, transportation, inventory, routing, pricing and maintenance that have been adopted to operational support of shared mobility systems. For instance, the problem of relocating bikes over time in a station-based bike sharing system can be formulated as service network design problem. We show that next to the coverage of routing, the problem formulation incorporates inventory and transportation decisions. The fact that the number of bikes is kept constant over time is depicted by asset management constraints. A matheuristic is proposed to solve this problem to near optimality. Tailored techniques are to be developed in order to cope with these complex problems.

## ■ WD-24

Wednesday, 15:30-16:15 - HFB|C

### Semi-Plenary Marco Lübbecke

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: Thorsten Koch

#### 1 - Optimization meets Machine Learning

Marco Lübbecke

Optimization, as a way to make "best sense of data" is a common topic and core area in operations research (OR), in theory and applications. Machine learning, being rather on the predictive than on the prescriptive side of analytics, is not so well known in the OR community. Yet, machine learning techniques are indispensable for example in big data applications. We start with sketching some basic concepts in supervised learning and mathematical optimization (in particular integer programming). In machine learning, many optimization problems arise, and there are some suggestions in the literature to address them with techniques from OR. More importantly, we are interested in the reverse direction: where (and how) can machine learning help in improving methods for solving optimization problems and what is it that we can actually learn? We conclude with an alternative view on this presentation's title, namely opportunities where predictive meets prescriptive analytics.

## ■ WD-25

Wednesday, 15:30-16:15 - HFB|D

### Semi-Plenary Martin Bichler

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: Andreas Fink

#### 1 - Market Design: A Linear Programming Approach

Martin Bichler

Market design uses economic theory, mathematical optimization, experiments, and empirical analysis to design market rules and institutions. Fundamentally, it asks how scarce resources should be allocated and how the design of the rules and regulations of a market affects the functioning and outcomes of that market. Operations Research has long dealt with resource allocation problems, but typically from the point of view of a single decision maker. In contrast, Microeconomics focused on strategic interactions of multiple decision makers. While early contributions to auction theory model single-object auctions, much recent theory in the design of multi-object auctions draws on linear and integer linear programming combined with game-theoretical solution concepts and principles from mechanism design. This led to interesting developments in theory and practical market designs.

The talk will first introduce a number of market design applications and show how discrete optimization is used for allocation and payment rules. These markets include industrial procurement, the sale of spectrum licenses, as well as cap-and-trade systems. In addition, we survey a number of theoretical developments and the role of integer and linear programming in recent models and market designs. Models of ascending multi-object auctions and approximation mechanisms will serve as examples. Finally, we will discuss limitations of existing models and research challenges. Some of these challenges arise from traditional assumptions about utility functions and social choice functions, which often do not hold in multi-object markets in the field. For example, financial constraints of bidders have long been ignored in theory, but they are almost always an issue in the field. Such deviations from standard assumptions lead to interesting theoretical questions, but also to very tangible problems in the design of markets.

## Wednesday, 16:30-18:00

### ■ WE-01

Wednesday, 16:30-18:00 - WGS|101

### Robust Combinatorial Optimization

Stream: Optimization under Uncertainty

*Parallel session*

Chair: Sven Krumke

#### 1 - A Robust Approach to Single-Allocation Hub Location Problems with Uncertain Weights.

Jannis Kurtz

The idea of min-max-min robustness is to calculate  $k$  different solutions of a linear combinatorial problem such that these solutions are worst-case optimal if we consider the respectively best of the calculate solutions in each scenario. This idea can be modeled as a min-max-min problem and improves the classical min-max approach. We extend the idea of min-max-min robustness to quadratic combinatorial problems and apply it to single-allocation hub location problems with uncertain weights.

#### 2 - Strategic and operational resource planning for emergency doctors

Manuel Streicher, Sven Krumke, Eva Schmidt

The German emergency system is based on doctors being sent out in certain specified cases, determined by a classification of different emergencies. This is in contrast to systems in other countries, where for instance paramedics handle almost all emergency cases. Emergency doctors are a costly resource and maximizing the coverage and minimizing the cost are two conflicting goals. Both, locating doctors and assigning them to cases need to be planned in a way that important constraints, such as a maximal response time can be guaranteed for a given quantile of the cases. In order to ensure a good performance of the whole system, good decisions have to be taken on a strategic as well as an operational level. On a strategic level emergency doctors need to be assigned to facilities which possibly have to be planned. When locating the doctors, several different constraints have to be taken into account, mainly the sufficient covering of the regions. This leads to a location or coverage problem with uncertain demand, since the actual number of emergencies is not known in advance. We present various models and solution approaches on the basis of robust optimization. The operational level involves the assignment of emergency doctors to specific emergencies and the planning of tours for emergency doctors. The emergencies occur over time and become known in an online fashion. Thus, decisions have to be made on the basis of incomplete data. We discuss various online settings based on reoptimization and other classical online policies. We also provide an offline model and algorithm, which can be used for a posteriori quality control and on the fly monitoring of solution quality. We present various computational results on the basis of real world data.

#### 3 - An Approximate Dynamic Programming Based Heuristic for the Stochastic Lot-Sizing Problem in Remanufacturing Systems

Sedat Belbag, Mustafa Çimen, Mehmet Soysal, Armagan Tarim

The recovery of used products has been receiving more attention due to the growing awareness on sustainable production. Remanufacturing is a widely accepted product reuse process in practice, by which the used products are recovered or updated to as good as new condition. The products are returned to the original equipment manufacturers due to various reasons such as end-of-life, false failure and warranty. The returned products are remanufactured to satisfy customer demands for new products. This study addresses a lot-sizing problem subject to the assumptions of capacitated production and remanufacturing, stochastic demand and returned products, and infinite planning horizon. The aim is to maximize the expected long-term discounted profit by deciding the amount of new products to be produced. The addressed lot-sizing problem is modelled as a Markov Decision Process. Dynamic Programming approach allows to obtain optimal solutions for small-sized instances of the problem. However, as the problem size increases, computation and memory requirements render Dynamic Programming approach infeasible. This study proposes an Approximate Dynamic

Programming based heuristic algorithm for the problem. Several numerical analyses are conducted to determine the optimal production plans using the DP method and to demonstrate the practical applicability and performance of the ADP-based algorithm.

## ■ WE-02

Wednesday, 16:30-18:00 - WGS|102

### Optimization Software

Stream: Software Applications and Modelling Systems  
*Parallel session*

Chair: Ulf Lorenz

#### 1 - Simheuristics and Learnheuristics: extending metaheuristics in stochastic and dynamic scenarios

Angel A. Juan, Javier Faulin, Laura Calvet, Juan-Ignacio Latorre-Biel, Lorena Reyes-Rubiano

A large number of decision-making processes in real-life transportation, logistics, financial, and production applications can be modeled as NP-hard combinatorial optimization problems (COPs). These COPs are frequently characterized by their large-scale sizes and the need to obtain high-quality solutions in short computing times. This imposes some severe limitations on the use of exact methods, so alternatives such as metaheuristics are required instead. Still, metaheuristics usually assume deterministic and static environments. These are strong assumptions which are not usually in accordance with modern systems, typically characterized by high levels of uncertainty and dynamism. By combining simulation and machine-learning techniques with metaheuristics, simheuristic and learnheuristic algorithms are able to cope with real-life uncertainty and dynamism in a natural way. Several examples contribute to illustrate the main ideas behind these emerging concepts.

#### 2 - Biased Randomization Procedures in Metaheuristics to Solve Stochastic Combinatorial Problems in Transportation and Logistics

Javier Faulin, Angel A. Juan, Adrian Serrano, Lorena Reyes-Rubiano, Juan-Ignacio Latorre-Biel

The procedures to randomize metaheuristics are becoming very popular to solve stochastic combinatorial problems related to transportation and logistics. Among the myriads of methods to introduce randomization in an algorithm the use of biased statistical distributions is producing very good results. These successful outcomes are achieved by means of a biased random guidance of the metaheuristics which explore the most promising areas of the feasible region. After a general description of this technique, some applied cases are presented, making strong emphasis in transportation and logistics applications. Thus, these examples illustrate how Monte Carlo simulation and discrete-event simulation can be used to deal with the stochastic performance of many real problems which are present in current companies.

#### 3 - Yasol: An open-source solver for Quantified Integer Program problems

Ulf Lorenz, Michael Hartisch

Quantified integer linear programs (QIPs) are linear integer programs (IPs) 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. In order to solve the QIP optimization problem, where the task is to find an especially attractive winning strategy, we examine the problem's hybrid nature and present the open source solver Yasol that combines linear programming techniques with solution techniques from game-tree search.

## ■ WE-03

Wednesday, 16:30-18:00 - WGS|103

### Vehicle routing - Exact Methods

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: Taieb Mellouli

#### 1 - Multi-Commodity Two-Echelon Vehicle Routing Problem with Time Windows

Fardin Dashty Saridarq, Nico Dellaert, Tom van Woensel, Teodor Gabriel Crainic

This paper introduces and studies the multi-commodity two-echelon capacitated vehicle routing problem with time windows. This problem considers non-substitutable demands into account by introducing commodities for the two-echelon capacitated vehicle routing problem where these commodities are transferred from depots to satellites (first echelon) and then transferred from satellites to the final customers (second echelon). We propose an arc-based model and a path-based model using the traditional modelling approaches. Moreover, exploiting the structure of the problem, we propose a combined arc-path-based model which defines arc-flow variables for the routing at the first echelon and path-flow variables for the routing at the second echelon. A branch-and-price algorithm is developed which works on the arc-path-based model. We test the performance of the proposed algorithm through a computational study on problem instances.

#### 2 - Vehicle Scheduling vs. Vehicle Routing: Efficient network flow-based mathematical models and contrasts in structure and practical requirements

Taieb Mellouli

Although vehicle routing and vehicle scheduling problems (VRP, VSP) seem to share a very common structure (chaining locations or trips into routes/rotations), state-of-the-art methods for practical constraints are based on mathematical programming for the second, but large instances for routing problems are still solved heuristically.

A network with (time-)space nodes and explicit arc connections is acyclic only for VSP due to irreversible time progress. Connections can be represented implicitly by introducing connection (time)lines at stations, leading to more efficient models for VSP. In order to efficiently solve hard versions of VSP and rotation building (multiple types and depots for buses, cyclic maintenance requirements for trains), the author developed crucial techniques for aggregating dead-head trips and resource paths based on computing latest-first-matches between connection lines and introducing multiple resource-state dependent connection lines.

For vehicle routing, flow models suffer of subtours and lot of symmetry. One way to break subtours is to couple commodity flows (loads, linehaul/delivery & backhaul/pickup) with vehicle routes' flow. We introduce the notion of DP-turns and restrict their average number per tour by a parameter  $\tau$ :  $\tau=1$  means that linehaul is always before backhaul (VRPB) and the larger is  $\tau$  the more general is the VRP version towards VRPDP. Recognizing route parts with linehaul and backhaul loads allows for an efficient modeling of restricted mixing (RM). Results for up to 100 nodes using Gurobi show that restricted versions are solved more efficiently—better tour quality to break symmetry! A special LP fixing heuristic leading to nearly optimal solutions enables to solve larger models up to 200 nodes for VRPRMDP.

## ■ WE-04

Wednesday, 16:30-18:00 - WGS|104

### Confluence of Discrete and Continuous Network Optimization

Stream: Graphs and Networks

*Parallel session*

Chair: Andreas Karrenbauer

#### 1 - Near-Optimal Approximate Shortest Paths and Transshipment in Distributed and Streaming Models

Ruben Becker, Andreas Karrenbauer, Sebastian Krinninger, Christoph Lenzen

We present a method for solving the shortest transshipment problem—also known as uncapacitated minimum cost flow—up to a multiplicative error of  $1 + \epsilon$  in undirected graphs with polynomially bounded integer edge weights using a tailored gradient descent algorithm. Our gradient descent algorithm takes  $\epsilon^{-3}$  polylogn iterations, and in each iteration it needs to solve the transshipment problem

up to a multiplicative error of polylog  $n$ , where  $n$  is the number of nodes. In particular, this allows us to perform a single iteration by computing a solution on a sparse spanner of logarithmic stretch. Using a careful white-box analysis, we can further extend the method to finding approximate solutions for the single-source shortest paths (SSSP) problem. As a consequence, we improve prior work by obtaining better results in several distributed models of computation. This includes for the first time matching a well-known lower bound in the CONGEST model up to logarithmic factors for the SSSP problem.

## 2 - Phase unwrapping for SAR interferometry using undirected shortest transshipments

*Andreas Karrenbauer*

We combine methods from combinatorial and continuous optimization to solve large scale optimization problems for constructing digital elevation models. Synthetic Aperture Radar (SAR) interferometry is a remote sensing technique to acquire information of the landscape from aircraft or satellite by measuring phase differences in signals reflected from the surface. Since the phase differences are wrapped modulo  $2\pi$ , there is some ambiguity in reconstructing the elevations of the grid points on the surface and the smoothest among all possibilities is chosen as good hypothesis, i.e., the solution with the minimum total absolute height differences between neighbors in the grid. This can be modeled as an undirected shortest transshipment problem. We demonstrate how a gradient descent can be combined with a combinatorial dual ascent algorithm for directed min-cost flows to solve this problem efficiently.

## 3 - Two Results on Slime Mold Computations

*Pavel Kolev, Ruben Becker, Vincenzo Bonifaci, Andreas Karrenbauer, Kurt Mehlhorn*

We present two results on slime mold computations. The first one treats a biologically-grounded model, originally proposed by biologists analyzing the behavior of the slime mold *Physarum polycephalum*. This primitive organism was empirically shown by Nakagaki et al. to solve shortest path problems in wet-lab experiments (Nature'00). We show that the proposed simple mathematical model actually generalizes to a much wider class of problems, namely undirected linear programs with a non-negative cost vector.

For our second result, we consider the discretization of a biologically-inspired model. This model is a directed variant of the biologically-grounded one and was never claimed to describe the behavior of a biological system. Straszak and Vishnoi showed that it can epsilon-approximately solve flow problems (SODA'16) and even general linear programs with positive cost vector (ITCS'16) within a finite number of steps. We give a refined convergence analysis that improves the dependence on epsilon from polynomial to logarithmic and simultaneously allows to choose a step size that is independent of epsilon. Furthermore, we show that the dynamics can be initialized with a more general set of (infeasible) starting points.

interdependent long-run investments of airlines and airports within a market environment.

In particular, on the first level we assume airports that choose their runway capacity extensions together with their level of charges. Airports anticipate the behavior of airlines that will (i) invest in their aircraft fleet on the second level, (ii) schedule their (existing and new) fleet on the third level, and (iii) sell their tickets on several markets on the fourth level. Obviously, all four levels are highly interconnected. For instance, the number of sold tickets on the fourth level depends on the aircraft that is scheduled on the considered connection on the third level, which in turn is influenced by investment decisions on the first and second level. On the opposite, optimal long-run investments depend on profits realized on the ticket market on the fourth level as well as on current policy regulations.

Given this complex interdependency, we reformulate the original four-level problem and solve the resulting single-level problem with a sub- and master problem decomposition. Finally, we illustrate the results of our market model and quantitatively evaluate different market regulations in a first case study.

## 2 - The Flight Planning Problem with Variable Speed

*Marco Blanco, Ralf Borndörfer, Nam Dung Hoang, Thomas Schlechte*

In the Flight Planning Problem, which generalizes the Shortest Path Problem, the objective is to compute a minimum-cost flight trajectory between two airports. Given are, among other factors, the aircraft's type and weight, the departure time, and a weather prognosis. The objective function is the sum of fuel costs, time costs, and overflight fees.

Traditionally, Flight Planning algorithms assume that aircraft fly either at a constant speed (with respect to the surrounding air mass) or use at every iteration a formula that returns a "good" flight speed as a function of the ratio between fuel price and time costs, and the aircraft's current weight and altitude.

In this talk, we present a novel Dynamic Programming algorithm for solving the Flight Planning Problem to optimality in the case of constant flight speed. We introduce a few variants of the algorithm which consider speed as a free variable, and present corresponding computational results.

## 3 - Lessons learned on Robust Efficiency of Airline Crew Schedules

*Lucian Ionescu, Natalia Klierer*

In airline operations, resource schedules are under constant exposure to unforeseen disruptions. In the aftermath, schedule infeasibility and delays often necessitate expensive recovery actions. Consequently, real costs for an airline may be considerably higher than planned costs. Narrowing this gap is the main goal of the concept of robust efficiency: schedules are generated in a way that they are robust against delay occurrences while preferably maintain their efficiency in terms of planned costs. Schedule robustness can be achieved by increasing the degree of stability or flexibility. While stability targets at operating schedules 'as planned' and thus demands relatively good delay predictions, an increasing degree of flexibility offers more possibilities to react to unanticipated delays.

In this setting, we discuss lessons learned from a recent research project on the incorporation of stability and flexibility into airline crew schedules in connection with delay prediction studies. The main focus is on mutual impacts between stability and flexibility.

## ■ WE-05

Wednesday, 16:30-18:00 - WGS|104a

### Planning and Scheduling in Air Transportation

Stream: Traffic, Mobility and Passenger Transportation  
*Parallel session*

Chair: *Lucian Ionescu*

#### 1 - Airport Capacity Extension, Fleet Planning, and Optimal Aircraft Scheduling in a Four-Level Market Model: On the Effects of Market Regulations

*Martin Weibelzahl, Mathias Sirvent*

Given the liberalization in the airline sector, private airlines invest in new aircraft on the basis of expected market developments and future profits. In contrast, regulated airports choose their runway capacity investments in anticipation of future fleet planning of airlines and corresponding passenger growth. While capacity extensions of airports and fleet planning of airlines are highly interconnected, traditional planning processes typically ignored such an interplay. Therefore, in this paper we present a four-level market model that directly accounts for

## ■ WE-06

Wednesday, 16:30-18:00 - WGS|105

### Cycle Packings

Stream: Graphs and Networks

*Parallel session*

Chair: *Peter Reicht*

#### 1 - Fullerene - Relationship between Maximum Cycle Packing and Independence Set of Dual Graph

*Stefan Stehling*

The field of applications for Fullerenes ranges from medical use to photovoltaic installations: There is an intense research throughout many areas ongoing. As a fullerene can be represented by so called Fullerene graphs their chemical properties might be related to graph-theoretical properties of the corresponding polyhedral graphs. The lecture will focus on the relationship between maximum cycle packings in fullerene graphs and independence sets of the corresponding dual graph. The results are used to implement an efficient algorithm to apply exact maximum cycle packings for small fullerenes.

## 2 - On Maximum Cycle Packings in Halin Graphs using Wheel Decomposition

Christin Otto

Let  $G=(V,E)$  be an undirected graph. The maximum cycle packing problem is to find a collection  $C=C_1, \dots, C_s$  of edge-disjoint cycles  $C_j$  in  $G$  such that the cardinality  $s$  of the collection is maximum. In general, this problem is NP-hard. For the class of Halin graphs an algorithm is presented for computing  $C$ . The procedure is based on splits and a decomposition of Halin graphs into wheels. Since the components can be represented by a decomposition tree (similar to SPQR-trees) the approach can be considered as a generalization of decomposing graphs into blocks and blocks into 3-connected components.

## 3 - Spontaneous postman problems

Peter Recht

In this lecture we address "Spontaneous Postman Problems". In this type of routing problems the postman selects subsequent streets of his tour by a willy-nilly strategy. In such a way it differs from well known "classical" postman-problems, where the postman's transversal of streets is performed according to some routing plan. This problem appears in real world tour planning, if the selection of subsequent traversals is done careless. Such a choice can be observed in the display of tours in a museum or tours in trade fair. The spontaneous character of such a choice leads to the basic question how to partition a street network into different districts in such a way, that one can guarantee, that each district is served if the postman is "spontaneous". The structural problems of the network that arise within this framework are closely related to the investigation of local traces and maximum edge-disjoint cycle packings in graphs.

## ■ WE-07

Wednesday, 16:30-18:00 - WGS|106

### Foundations of Linear and Integer Programming (I)

Stream: Discrete and Integer Optimization

Parallel session

Chair: Stefan Weltge

#### 1 - Beyond TU-ness: A Strongly Polynomial Algorithm for Bimodular Integer Linear Programming

Stephan Artmann, Robert Weismantel, Rico Zenklusen

We present a strongly polynomial algorithm to solve integer programs given by inequality constraints, where the constraint matrix  $A$ , the right-hand side and the objective function vector are integral and  $A$  is of the following type: It has full column rank  $n$  and the determinants of all quadratic ( $n$  times  $n$ )-sub-matrices of  $A$  are bounded by 2 in absolute value.

We thus obtain an extension of the well-known result that integer programs with constraint matrices that are totally unimodular are solvable in strongly polynomial time.

#### 2 - On the number of distinct rows of a matrix with bounded sub-determinant

Christoph Glanzer, Robert Weismantel, Rico Zenklusen

Let  $A$  be an integral matrix with  $m$  rows and  $n$  columns whose maximal submatrices have a determinant of at most  $\delta$  in absolute value. Assume that  $A$  attains full column-rank and that all of its rows are distinct. What is the maximal number of rows such a matrix can have? We prove that for fixed  $\delta$ ,  $m$  is bounded by  $O(n^2)$ . This is a generalization of the well-known result of Heller that totally unimodular matrices admit at most  $O(n^2)$  distinct rows. We also present extensions of our result to cases where  $\delta$  is a function of  $n$ .

## 3 - A polynomial algorithm for linear problems given by separation oracles

Sergei Chubanov

In this talk, we will consider an algorithm for solving systems of linear inequalities given by separation oracles. Without loss of generality, we assume that the system in question is homogeneous, i.e., that it defines a cone. We are looking for a nonzero solution of this system. The algorithm is based on a procedure for finding sufficiently short convex combinations of the rows of the coefficient matrix. Whenever such a combination is found, the algorithm performs a linear transformation of the space which depends on this convex combination. The running time of the algorithm is bounded by a polynomial in the number of variables and in the maximum binary size of an entry of the coefficient matrix, provided that the separation oracle is a polynomial algorithm.

## ■ WE-08

Wednesday, 16:30-18:00 - WGS|107

### Public Transportation Planning 2

Stream: Traffic, Mobility and Passenger Transportation

Parallel session

Chair: Christian Puchert

#### 1 - Demand-Driven Line Planning with Selfish Routing

Malte Renken, Amin Ahmadi Digebsara, Ralf Borndörfer, Gjuvenc Sahin, Thomas Schlechte

Bus rapid transit systems in developing and newly industrialized countries are often operated at the limits of passenger capacity. In particular, demand during morning and afternoon peaks is hardly or even not covered with available line plans. In order to develop demand-driven line plans, we use two mathematical models in the form of integer programming problem formulations. While the actual demand data is specified with origin-destination pairs, the arc-based model considers the demand over the arcs derived from the origin-destination demand. In order to test the accuracy of the models in terms of demand satisfaction, we simulate the optimal solutions and compare number of transfers and travel times. We also question the effect of a selfish route choice behavior which in theory results in a Braess-like paradox by increasing the number of transfers when system capacity is increased with additional lines.

#### 2 - Traffic management heuristics for bidirectional line segments on double-track railway lines

Norman Weik, Stephan Zieger, Nils Nießen

In this paper traffic management strategies for disruption-caused inaccessibility of one track on double-track railway lines are analyzed. In practice, this type of failure gives rise to heavily loaded temporarily bidirectional line segments. Building on previous results for polling systems with  $k$ -limited service discipline and non-zero switchover times heuristic rules for optimally switching the orientation of the bidirectional segment are investigated. QoS-standards for the waiting time enforcing delay constraints for both orientations as well as asymmetric traffic load, e.g. resulting from rerouting of train services to other lines, are accounted for.

Nonpriority systems are analyzed based on approximate formulae for the mean waiting time of queues. The approximations make use of results for 1-limited and exhaustive service policy. In addition, we numerically analyze polling systems with two priority classes of trains. The inclusion of different train priority classes exhibiting different QoS-standards with respect to waiting times provides a new perspective setting the problem apart from existing polling applications in transportation modeling, e.g. traffic intersections or automated vehicle operation.

The performance of the heuristic management strategies are assessed by comparing the class-specific waiting times to the optimal solution obtained by solving the train scheduling problem for the bidirectional line segment. In the optimization approach the problem is solved both globally and with a limited time horizon. The input parameters for the tests are based on real-world train operation data including driving times as well as headway times resulting from interlocking constraints.

### 3 - Detecting, Interpreting and Exploiting Structures in Integrated Public Transport Planning Problems

*Christian Puchert, Marco Lübbecke, Philine Schiewe, Anita Schöbel*

In this talk, we investigate traffic planning problems in public transport such as line planning, timetabling, vehicle scheduling, and passenger routing. Instead of solving the planning steps sequentially, we consider them simultaneously as one single integrated planning problem.

Such an integrated problem has a structure which is also reflected by corresponding mixed integer programming (MIP) models, whose coefficient matrix then has a (bordered) block diagonal structure reflecting the single planning steps. Besides, the steps themselves may again decompose into such a structure - a line planning model, e.g., may itself in turn decompose into the corresponding lines.

Besides the "obvious" structure that reflects the planning steps, the model may also bear "hidden" structures which are not known to the modeler. We employ structure detection methods based on graph models to find such structures. Furthermore, we analyze the detected structures w.r.t. to the network topology, and investigate in how far a variation on the input data affects the MIP model as well as the decomposition.

Last, we apply a Dantzig-Wolfe decomposition and branch-and-price approach on the models and their structures. We give a computational comparison on the solver performance between different structures as well as to a standard branch-and-cut approach.

## ■ WE-09

Wednesday, 16:30-18:00 - WGS|108

### Discrete Optimization by Semidefinite Methods (i)

Stream: Discrete and Integer Optimization  
Parallel session

Chair: *Angelika Wiegele*

#### 1 - A Modified Bundle Method for SDP with Exact Subgraph Constraints

*Elisabeth Gaar, Malwina Duda, Franz Rendl*

The stable set problem, the coloring problem and the max-cut problem are three different famous combinatorial optimization problems. All the problems are downward monotone, that is restricting the problem to a subgraph yields an instance of the same problem on a smaller graph. We use this fact and define so called exact subgraph constraints. For a certain subgraph the exact subgraph constraint ensures, that the submatrix of the calculation of the relaxation corresponding to the subgraph is in the convex hull of all stable set, max-cut or coloring matrices of the subgraph respectively. Therefore, in order to get an improved bound for the above problems, one can start with the original relaxation and include the exact subgraph constraints for many small - wisely chosen - subgraphs. We call a problem of such form P1. Solving P1 is very time-consuming with off-the-shelf solvers, hence it requires alternative solution methods. By building the Lagrangian dual of P1 with respect to the exact subgraph constraints, one gets an optimization problem P2, where the objective function can be split (with common linear variables) into a part which captures the SDP and a second linear part. To P2 a specialized version of the bundle method, namely the bundle method with easy sum components, can be applied in a very natural way. In the resulting iterative solution method, in each iteration one has to solve an SDP with few constraints (for the oracle) and a very nicely structured QP or alternatively a larger LP (for getting the new trial point). In the talk we will discuss different solution methods for this QP and see that our method significantly improves the running times to solve P1 to our desired accuracy.

#### 2 - Solving Extended Single Row Facility Layout Problems Using a Spectral Bundle Method

*Anja Fischer, Mirko Dahlbeck, Frank Fischer*

In this talk we consider the Single Row Facility Layout Problems (SR-FLP) and extensions of it. Given a set of one-dimensional departments with positive lengths and pairwise transport connections between them, the aim is to determine an order of the departments along a line such

that the weighted sum of the distances between the departments is minimized. We present a semidefinite programming formulation for the SRFLP which can handle asymmetric transport weights. Furthermore, the input and output positions might be arbitrary placed along the departments and one might specify clearance conditions between the departments. A relaxation of this model is solved using a spectral bundle method which allows to obtain good lower bounds rather quickly even for large instances. We compare our results to further solution approaches from the literature.

#### 3 - DADAL - Improving Alternating Direction Augmented Lagrangian Algorithm for SDP by a Dual Step

*Angelika Wiegele, Marianna De Santis, Franz Rendl*

Alternating direction augmented Lagrangian (ADAL) methods turned out to be effective for solving semidefinite programming problems in standard form. These methods usually perform a projection onto the cone of semidefinite matrices at each iteration. With the aim of improving the convergence rate of these methods, we propose to update the dual variables before the projection step. Numerical results are shown on both random instances and on instances for the computation of the Lovasz theta number, giving some insights on the benefits of the approach.

## ■ WE-10

Wednesday, 16:30-18:00 - WGS|108a

### Scheduling and Resource Management under Uncertainty

Stream: Discrete and Integer Optimization  
Parallel session

Chair: *Nicole Megow*

#### 1 - The Itinerant List Update Problem

*Kevin Schewior, Neil Olver, Kirk Pruhs, René Sitters, Leen Stougie*

We introduce the Itinerant List Update Problem (ILU), in which items from a linear list are sequentially requested. In response to a request, the pointer, initially positioned at the front of the list, has to be moved to the corresponding item. Hereby, at all times, the item at the pointer's position may be swapped with an adjacent one. The goal is to minimize the total number of pointer moves and swaps. This problem is a relaxation of the classic List Update (LU) problem in which the pointer no longer has to return to a home location after each request. The motivation to introduce ILU arises from the application of track management in Domain Wall Memory. We first show an  $\Omega(\log n)$  lower bound on the competitive ratio for any randomized online algorithm for ILU. This shows that online ILU is harder than online LU, for which deterministic  $O(1)$ -competitive algorithms, like Move-To-Front, are known. We then show that ILU is essentially equivalent to a variation of the Minimum Linear Arrangement Problem (MLA), which we call the Dynamic Minimum Linear Arrangement (DMLA) problem. We next discuss algorithms for DMLA, including an offline polynomial-time  $O(\log^2 n)$ -approximation.

#### 2 - Submodular Secretary Problems: Cardinality, Matching, and Linear Constraints

*Andreas Tönnis, Thomas Kesselheim*

We study various generalizations of the secretary problem with submodular objective functions. Generally, a set of requests is revealed step-by-step to an algorithm in random order. For each request, one option has to be selected so as to maximize a monotone submodular function while ensuring feasibility. For our results, we assume that we are given an offline algorithm computing an alpha-approximation for the respective problem. This way, we separate computational limitations from the ones due to the online nature. When only focusing on the online aspect, we can assume  $\alpha = 1$ .

In the submodular secretary problem, feasibility constraints are cardinality constraints, or equivalently, sets are feasible if and only if they are independent sets of a  $k$ -uniform matroid. That is, out of a randomly ordered stream of entities, one has to select a subset size  $k$ . For this problem, we present a  $0.31\alpha$ -competitive algorithm for all  $k$ , which asymptotically reaches competitive ratio  $\alpha/e$  for large  $k$ .



Furthermore, we consider online submodular maximization with random order of arrival subject to other types of constraints. We give a constant competitive algorithm for the submodular secretary problem subject to a matching constraints, which also covers the case where sets of items are feasible if they are independent with respect to a transversal matroid. Additionally, we give an algorithm for linear packing constraints. In this case, we parameterize our result in the column sparsity and minimal capacity ratio in a constraint. Here our guarantee depends on whether those parameters are known to the algorithm in advance or not.

### 3 - Greedy Algorithms for Unrelated Machines Stochastic Scheduling

Marc Uetz, Varun Gupta, Benjamin Moseley, Qiaomin Xie

We derive the first performance guarantees for a combinatorial online algorithm that schedules stochastic, nonpreemptive jobs on unrelated machines to minimize the expectation of the total weighted completion time. Prior work on unrelated machine scheduling with stochastic jobs was restricted to the offline case, and required sophisticated linear or convex programming relaxations for the assignment of jobs to machines. Our algorithm is purely combinatorial, and therefore it also works for the online setting. As to the techniques applied, this paper shows how the dual fitting technique can be put to work for stochastic and nonpreemptive scheduling problems.

## ■ WE-11

Wednesday, 16:30-18:00 - WGS|005

### Vehicle Scheduling

Stream: Logistics and Freight Transportation

Parallel session

Chair: Martin Pouls

#### 1 - Exploration of Flexibility Schemes for Time Window Management

Charlotte Köhler, Jan Fabian Ehmke, Ann Campbell

In the competitive world of online retail, customers can choose from a selection of delivery time windows on retailer websites. When accepting customer requests, retailers can build tentative delivery routes and check if each customer can be accommodated feasibly with the remaining delivery capacity. Since demand is not known at the beginning of booking process, but becomes available incrementally over time, the acceptance of an order request can restrict the ability of accommodating future requests significantly.

In this presentation, we investigate different schemes for more flexible time window management. The general idea is to adapt time window offerings based on characteristics of the evolving route plan to enable more customers to be served. Extending customer acceptance mechanisms from the literature, we consider the remaining logistics capacity, the time of the request relative to the booking horizon, and the customer location in the decision of how many different time windows and what time window widths to offer to the customer. We investigate the impact of these ideas on the number of served customers given the demand structure of order data from an e-grocer in Berlin, Germany. We also develop and demonstrate different measures of customer service to further compare the performance of different adaptive schemes.

#### 2 - A randomised three-stage algorithm for the multiple depot vehicle scheduling problem

Sarang Kulkarni, Mohan Krishnamoorthy, Andreas Ernst, Abhiram Ranade, Rahul Patil

The multiple depot vehicle scheduling problem (MDVSP) in the public transport industry is a well-known NP-hard problem. The MDVSP deals with the sequencing and assignment of a set of timetabled trips to buses, which are stationed at different depots. A sequence of the trips corresponds to a schedule for a bus to which the trips are assigned. A bus may need to travel empty from the end location of one trip to the start location of its next trip. Such bus trips are referred to as deadheading trips or repositioning trips. One of the objectives of the MDVSP is to minimise deadheading and hence, the total deadheading cost. The second MDVSP objective is to minimise the number of buses that are required for covering all the trips. We have developed a three-stage algorithm to solve the MDVSP. The first stage converts the MDVSP to

a single depot vehicle scheduling problem using a suitable relaxation procedure. In the second stage, a feasible solution is obtained using the solution to the single depot problem from the first stage. The third stage involves an iterative procedure to improve the initial feasible solution. Each iteration involves randomly dividing the entire scheduling horizon into two partitions. Improvements to the solution, if any, can be obtained by determining the optimal connections that 'join' the two partitions. An assignment formulation is solved to get the optimal connections. The best of these solutions obtained in the second and third stage is selected as the solution to the MDVSP. We tested the algorithm using benchmark instances. The solutions are compared with those that are obtained using standard solvers as well as existing heuristic-based solution approaches.

#### 3 - A Branch-and-Price Algorithm for the Scheduling of Customer Visits in the Context of the Multi-Period Service Territory Design Problem

Martin Pouls, Matthias Bender, Jörg Kalcsics, Stefan Nickel

Many companies employ field representatives to provide services at their customers' sites on a regular basis. Consider, for instance, the delivery of goods to retailers or regular technical maintenance tasks. In these applications, the entire region under study is subdivided into service territories, with one field representative being responsible for all customers in a territory. At a tactical planning level, customer visits within each service territory must be scheduled over a given planning horizon. The goal is to determine a valid visit schedule for each customer that meets customer-specific requirements such as visiting rhythms. In addition, the schedule must achieve a balanced daily and weekly workload. Lastly, compactness is important, as field representatives need to travel to their customers, and thus visits on the same day should be geographically concentrated.

In this talk we present a column generation formulation of the resulting scheduling problem and propose an exact branch-and-price algorithm. Our method incorporates specialized acceleration techniques, such as a fast pricing heuristic and a symmetry handling strategy. The latter aims to reduce the symmetry inherent to the model by fixing variables and thereby eliminating symmetric solutions from the search tree.

We perform extensive experiments on test instances based on real-world data in order to evaluate the different algorithmic components, such as branching variable selection and symmetry handling. Compared to the commercial general purpose mixed integer programming solver Gurobi, our algorithm achieves a significant speedup and is able to solve instances with up to 55 customers and a planning horizon of 4 weeks to optimality in a reasonable running time.

## ■ WE-12

Wednesday, 16:30-18:00 - WGS|BIB

### Hackathon: Gurobi-TomTom Mobility Maximization Mission Prize Award Session

Stream: Business Track

Parallel session

Chair: Heiko Schilling

#### 1 - Gurobi-TomTom-Hackathon Prize Awards

Heiko Schilling

This session presents the ideas and implementations of the participants of the Gurobi-TomTom Hackathon "Mobility Maximization Mission" (GTM3). At the end of the session, the jury will announce the winners and hand over the prizes.

## ■ WE-13

Wednesday, 16:30-18:00 - RVH|I

### Forecasting Algorithms & Methodology

Stream: Business Analytics, Artificial Intelligence and Forecasting

Parallel session

Chair: Sven F. Crone

## 1 - Generalized Lasso for Weight Regularization in Forecast Combination

Thomas Setzer, Sebastian Blanc

This work considers the regularization of weightings in group forecasts. Empirical studies regularly reveal that a simple averaging (SA) over a group of forecasts outperforms the best individual forecast. It is also found that SA typically performs better out of sample than weights learned from past error observations. The latter finding is due to the instability of learned weights that are sensitive to randomness in limited training data. The weighting scheme most sensitive to training data is the least squares solution that determines so-called optimal weights (OW). Some work has been published that show that a linear combination of OW and SA, i.e., the proportional shrinkage of OW towards SA, can beneficially trade-off the high bias of SA and the high sampling-based variance of OW and improve the accuracy achieved with either one of the individual weighting schemes. We propose the non-linear shrinkage of OW towards SA by penalizing the absolute sum of weight deviations from equal weights using the Generalized Lasso. Based on cross-validation results in Monte-Carlo simulations we provide guidelines when Combination Lasso asymptotically outperforms OW, SA and linear shrinkage.

## 2 - Efficiency improvement by employing forecast correction in judgmental revisions

Florian Knöll

Accuracy of forecasts is essential for financial services within corporations. In business corporations, experts in distributed subsidiaries usually forecast judgmentally cash flows for corporate risk management. As of the importance of cash flow forecasts in corporate risk management, techniques for data-driven forecast correction are applied. Often the forecast correction techniques apply solely statistical methods based on historical data and the consideration of organizational effects is entirely missing.

In accounting the forecast accuracy depends on statistics like lead time, but also on important organizational conditions such as targets of return margin. The author argues that the disregard of organizational information in forecast correction techniques misses opportunities that are truly impacting forecast efficiency. Forecast efficiency provides a statistical method to measure the amount of structure within forecasts and corrected forecasts.

However, empirical results not only show that the incorporation of organizational information is crucial to determine forecasts with suspicious pattern that are unaligned with planned margin targets. They also show that correction techniques can utilize organizational effects to improve forecast efficiency. The reduction of inefficient pattern shows that organizational forecast correction is superior to basic statistical approaches.

## ■ WE-14

Wednesday, 16:30-18:00 - RVH|II

### Analytics in Retail and Digital Commerce II

Stream: Business Analytics, Artificial Intelligence and Forecasting

Parallel session

Chair: Henning Nobmann

#### 1 - The Modelling and Assessment of Online Customer Interaction, Customer Journeys and Churning

Bernhard Luther, Nicola Winter

We present a strategy to forecast and assess customer behaviour in the field of e-commerce. Starting point is the assignment of all actors in a market to an exhaustive set of potentially accessible users. Usually, only a small part of this set belongs to real customers in the context of commercial transactions. The user information generated by arbitrary online-interaction is much more voluminous than the customer data collected. Typical customer profiles - regular customers as well as change customers and churners - can be generalised to corresponding user profiles. However customer data is much better structured than the naturally granular, heterogeneous and often incomplete data of arbitrary users. These users cannot be connected in a simple way with standardised monetary indicators like the customer lifetime value

(CLV). In consequence an effective exploitation of unstructured user data requires explorative and descriptive methods of correction and classification as well as statistical limitations arising from the heterogeneity of the data. As a clear focus the mean- and short-term user identification in the context of an effective classification is discussed. The main goal is to improve the representation and description of customer journeys together with an effect analysis of marketing activities. The traceable "journey" of all users hardly differs. Nevertheless, it might be the main base for decisions about general marketing campaigns and individual offers. Robust inferences on the base of many short-term user steps are an important goal. In this contribution, a case study of an online short break internet platform serves as an example.

#### 2 - The relationship between behaviors in real life and buying behaviors on the electronic commerce site

Kei Takahashi

In this paper, we focus on the relationship between behaviors in real life and buying behaviors on the fashion EC site. The proprietor of the EC site desire that users in their sites enrich their lives through purchasing via their own sites. In Japan, people enriching their real lives are called "Riajyu". These people tend to have some activities or parties, specifically fireworks display, sea bathing, and barbecue, Christmas, cherry-blossom viewing and Halloween parties. However, the proprietor of the EC site did not know which fashion items Riaju users tend to purchase on the EC site, or weather heavy users tend to have the some activities or parties. Then the proprietor of the EC site conducted a questionnaire survey for users including questions regarding to users' fashion perspectives and sense of their values. Using questionnaire result and point of sales with identifiers data, we construct a statistical model via Bayesian network and categorical factor analysis. As a result of the analysis, we found that Riajyu people tend to purchase not clothes but fusion accessories, e.g. hats.

#### 3 - Analyzing customer journeys in e-commerce

Henning Nobmann, Thomas Winter

We develop parametric models describing individual customer's journeys from first contact to an eventual purchase or defection in order to analyse the impact of different marketing channels on the retention and defection probabilities at different stages of the sales funnel. Our data consists of the logged webtraffic of a European short break online platform as well as data on their use of different marketing channels. As individual users are not readily identified from the data, we employ a hierarchical classification algorithm based on an ensemble of technical identifiers of differing accuracy and longevity to arrive at a fuzzy matching of our data to a predefined user base, allowing us to trace individuals' paths of interaction with the website through time. The goal is to evaluate and optimise the usage of different marketing channels throughout the sales funnel by estimating the conditional odds of retention/defection at different stages of the sales funnel with respect to the marketing tools targeting individual users. In addition, we aim to develop a clustering of users according to their search behaviour in order to be able to identify likely buyers or potential defectors that have a sufficiently high probability of retention if targeted with the appropriate channels early in their journey. Our data exemplifies various challenges in working with data on e-commerce: Identification of individual users depends on a multitude of cookies and internal IDs of varying quality, data formats are subject to continuous change, and the determinants of the often seemingly erratic behaviour of customers in the online market place are by no means obvious.

## ■ WE-15

Wednesday, 16:30-18:00 - RVH|III

### Safety and Security

Stream: Simulation and Statistical Modelling

Parallel session

Chair: Truong Son Pham

#### 1 - Developing a Generalized Cyber Security Quantification Model.

Vandana Kadam, Rakesh Verma

Cyber Security has gained a prime importance in today's dynamic computing world of networked-based, mobile-based, cloud based and IOT based environment. In such scenario, Generalized Cyber Security Model has become a need of an hour. In this research paper, a

Generalized Cyber Security Model is developed to calculate net effect of security. To arrive at the generalized model data collected using interviews and questionnaire. The dynamics in Cyber Security is depicted using Causal Loop Diagrams. The Stock and flow diagrams are developed. The outcome of this research work are various security parameters such as threats, risks, attacks and consequence of attack.

## 2 - Big-Data Approaches for Categorization of Ships based on AIS-Data

Max Krueger

The Automatic Identification System (AIS) is a system of cooperative VHF-radio exchange of navigational and ships' data for purposes of maritime safety, surveillance, and information. Since 2004, most of larger vessels are obligated to participate in AIS data exchange. Our contribution is based on a real-life data set, which contains collected AIS-data from 2014 and 2017 covering a few days to several weeks in different maritime areas, e.g., German Bight, English Channel, Vancouver Island, and others. After a brief descriptive statistical analysis of vessel types and properties in our geographical area of interest, we address the question, whether it is possible to categorize vessels based on AIS-data with respect to allegiance, behavior, and intention by means of Big-Data classification methods. As test case in our treatment, we try to categorize vessels on basis of their ships', positional, and motion AIS-data. Type- and identity-related data, which are also provided by AIS are used not as classification input but for reference and evaluation of categorization results. For deductive reasoning and statistical evaluation, we use the open-source tool KNIME Analytics Platform ([www.knime.org](http://www.knime.org)), which provides different classifications approaches, e.g., Naive Bayes, clustering approaches, Neural Networks, and others. An evaluation and comparison of classification results in this maritime Big data context concludes our contribution.

## 3 - Modeling the Causes for Terrorism: An Innovative Framework Connecting Impactful Events with Terror Incidents

Truong Son Pham, Gonzalo Barbeito, Martin Zsifkovits, Stefan Wolfgang Pickl

Terrorism has become an increasingly relevant issue accounting for significant social, economic and political impact. Due to powerful media coverage on the subject, a lot of information is now publicly available, although normally found in an unstructured form. This research aims to better understand the connection between a collection of impactful events, such as external or internal conflicts and military operations, with terror events and its motivations. To this end, a framework for performing predictive analytics was devised using distinguished OR-techniques, starting with an online news scraper, coupled with machine learning and natural language processing techniques, capable of clustering keywords into the main topics found in the news. The results of these adaptive algorithms, in the form of structured data, were later fed to a modeling technique capable of finding, to a certain degree, the connections between topics and terror events. The approach presented in this work adopts a perspective that, to the best of our knowledge, has not been previously seen in specialized literature. Furthermore, this methodology constitutes the groundwork for open source intelligence, capable of being applied on various similar domains, aiding in prediction of political and economic crises.

matrix. Recently, it was proved that despite this simplicity, the index tracking problem is strongly NP-hard. It was also demonstrated that the best-extension-by-one construction heuristic runs in time bounded by a fourth order polynomial, and that the running time of one iteration of the best-exchange-by-one improvement heuristic is of the same order. In the current work, construction and improvement methods with more favourable running times are developed. We demonstrate, in particular, how the running times can be reduced by one order of magnitude, with only modest increase in the tracking error. The merit of the new heuristics is justified through computational experiments applied to real-life stock market indices.

## 2 - Impact of algorithmic trading on market quality in Austria

Roland Mestel, Michael Murg, Erik Theissen

The prevalence of algorithmic trading is a key characteristic of today's securities markets. The effect of algorithmic trading activity on market quality has been the subject of intensive research. The results are somewhat ambiguous, partly because of limited data availability and endogeneity problems. We add to the literature by analyzing the impact on market quality of algorithmic trading in the Austrian stock market. Our paper makes several contributions to the literature. We use a data set in which the market share of algorithmic traders is identified through a classification of traders. Our sample spans 52 months and is thus considerably longer than the data sets used in almost all previous studies. The Austrian stock market has hitherto not been investigated. We thus provide out-of-sample evidence. Finally, we address the endogeneity problem using two different procedures. First, we employ a standard instrumental variables approach. Second, we implement the approach recently proposed by Lewbel (2012). This methodological approach is new to the literature on algorithmic trading. Our results indicate that an increase in the market share of algorithmic trading causes a reduction in quoted and effective spreads while quoted depth and price impacts are unaffected. These results are consistent with algorithmic traders acting as market makers. They do thus not justify regulatory approaches to curb algorithmic trading activity.

## 3 - Optimal Carbon Tax Scheme under Uncertainty in an Oligopolistic Market of Polluters

Andreas Welling

Carbon taxation is used by several countries to internalize the negative effects of carbon emissions to the emitters of carbon. In this article the effects of a carbon tax on an oligopolistic market of polluters are analyzed. With the help of a multi-criteria optimization model the optimal carbon tax rate is determined; first under certainty and then in presence of demand uncertainty. It is shown that demand uncertainty leads to a lower optimal carbon tax rate, while it simultaneously increases carbon emissions. Finally, the influence of a possible carbon emission reducing investment is analyzed with the help of a real option model.

## ■ WE-16

Wednesday, 16:30-18:00 - RBM|1102

### Finance III

Stream: Finance

Parallel session

Chair: Michael H. Breitner

#### 1 - Fast methods for the index tracking problem

Dag Haugland

In the index tracking problem, the goal is to select a restricted number of shares included in a stock market index, such that the portfolio resembles the index as closely as possible. Various definitions of closeness to the index have been proposed in the operations research literature. In the current work, the difference between the portfolio and the index, referred to as the tracking error, is measured by a quadratic function with the covariance matrix of the index returns as coefficient

## ■ WE-17

Wednesday, 16:30-18:00 - RBM|2204

### Strategic Planning in Health Care

Stream: Health Care Management

Parallel session

Chair: Brigitte Werners

#### 1 - Simulation-based Evaluation of Locations for Ambulances and Emergency Doctors

Pia Mareike Steenweg, Lara Wiesche, Brigitte Werners

In medical emergencies, patients require fast assistance. Therefore, ambulances and - in life-threatening cases - emergency doctors shall reach the emergency location within a given time frame. In Germany, they both travel separately and meet at the location, this is called Rendezvous-system. Thus far, tactical location and allocation planning models for emergency medical services focus on ambulances only. Our existing location model for ambulances determines sophisticated results based on data-driven empirically required coverage. The model incorporates temporal and spatial variations of emergency demand as well as variation of intraday travel times according to empirical studies. This contribution extends recent research by considering emergency doctors. Furthermore, we take into account increasing demand for services due to demographic change. Therefore, comprehensive

simulation studies investigate the optimal location of additional ambulances and the influence of extended availability of emergency doctors. The analysis applies real world data from a German city and takes dynamics and uncertainty into account. By performing What-if analyses respecting relevant criteria e.g. the coverage degree, the decision makers get improved insights on different options to allocate additional resources.

## 2 - A Location Problem for Emergency Healthcare Facilities

*Z. Pelin Bayindir, Cem Iyigün, Melike İşbilir*

In this study, we consider the problem of locating emergency healthcare facilities in urban areas. Upon emergency occurrence, patients are directed to any one of the emergency centers with a likelihood that depends on the travel time. Moreover, the survival, that represents the severity of the consequences of the emergency situation, is also probabilistic and is a function of the travel time. A mathematical model is constructed under the objective of maximizing expected number of survivors while determining the location of predetermined number of facilities. Characteristics of this model under certain situations, such as when a concave or convex survival function is used, or when the facility is located on a line or a network, are investigated. After presenting the analytical findings, we propose a Genetic Algorithm based solution approach to solve the model for locating healthcare facilities on a network. Lastly, we present its performance and findings through an extensive numerical study.

## 3 - Long-term personnel scheduling - A case study

*Lena Wolbeck, Natalia Kliewer*

Within 24/7 services like care facilities, the scheduling process and the resulting duty roster have a huge influence on the satisfaction of shift workers. To preserve and ideally raise the employee commitment, their needs have to be considered when creating a roster. There are many well-performing solution methods for varying kinds of personnel rostering problems, but these approaches mainly concentrate on a single planning period and marginally take the long-term perspective into account. Therefore, we look at a recurrent scheduling problem and simultaneously at the previous run. Furthermore, we incorporate accumulated key figures from all previous periods in our case study. Considering these aspects results in constraints beyond common constraints like working time regulations due to laws or labor agreements and, thus raises the model's complexity. In addition, a variety of individual regulations are taken into account. Examples of individual constraints are the working time resp. days off, the number of consecutive working days or requests for resp. against working on specific days or shifts. These limitations are personalized per employee and change every planning period. The aim of our study is to develop a solution approach for a generic personnel rostering problem considering the long-term aspect, in particular the passing from one planning period to the next. To examine the impact in practice, we test our methods in cooperation with a care facility for disabled people. This case study enables us to enhance the optimization model with respect to actual requirements and receive real-world data. Based on real-world data, a set of artificial data is generated to increase sample size and validate the findings.

## ■ WE-18

Wednesday, 16:30-18:00 - RBM|2215

## Models and Methods for Resource-Constrained Project Scheduling

Stream: Project Management and Scheduling

Parallel session

Chair: Norbert Trautmann

### 1 - A branch-and-bound procedure for the resource-constrained project scheduling problem with partially renewable resources and time windows

*Kai Watermeyer, Jürgen Zimmermann*

The resource-constrained project scheduling problem with partially renewable resources which is denoted as RCPSP/Pi has received relatively less attention by the research community to this day. For the RCPSP/Pi the capacity of each resource is given for an arbitrary subset

of time periods of the planning horizon whereby each activity with a demand for this resource only consumes it if the activity is executed during these periods. The partially renewable resources make it for instance possible to model problems in the area of complex labor regulations. Until now just a few solution procedures for the minimization of the project duration have been developed including only one exact solution method based on a branch-and-bound procedure for a more general problem. Our work focuses on the development of a branch-and-bound procedure for a generalization of the RCPSP/Pi which takes also minimal and maximal time lags between pairs of activities into consideration. The new enumeration scheme for the branch-and-bound procedure make use of the fact that the consumption of a resource by an activity is dependent on its start time. In each search node the earliest time-feasible schedule is determined by a modified label correcting algorithm where each activity is restricted to certain time points. If the calculated schedule is not resource-feasible the resource conflict is resolved by excluding further start time points of activities so that the given resource conflict cannot occur in following search nodes. To improve the performance of the branch-and-bound procedure we develop an efficient destructive lower bound based on the relaxation of schedule dependent start time windows.

### 2 - Markovian PERT networks: A new CTMC and benchmark results

*Stefan Creemers*

Markovian PERT networks were first studied by Kulkarni and Adlakha (1986), who use a continuous-time Markov chain (CTMC) to determine the exact distribution of the completion time of a project where activities have exponentially-distributed durations. All existing work on Markovian PERT networks adopts the CTMC of Kulkarni and Adlakha (1986) to develop scheduling procedures. We define a new CTMC that drastically reduces memory requirements when compared to the CTMC of Kulkarni and Adlakha (1986). Our CTMC can be used to develop scheduling procedures for a wide variety of problems that allow activities to be interrupted. If preemption is not allowed, these scheduling procedures can be used to obtain lower bounds. In addition, we also propose a new and efficient approach to structure the state space of the CTMC. These improvements allow us to easily outperform the current state-of-the-art in optimal resource-constrained project scheduling procedures, and to solve instances of the PSPLIB J90 and J120 data sets.

### 3 - CTMDP-Based Exact Method for Stochastic RCPSP with Uncertain Activity Durations and Rework

*Xiaoming Wang, Roel Leus, Stefan Creemers, Qingxin Chen, Ning Mao*

Many practical projects incorporate random rework, which leads to a stochastic project network structure. Until now, however, there have been only few works in the literature that have looked into this particular aspect of project planning and scheduling. In this paper, we consider a resource-constrained project scheduling problem (RCPSP) with exponentially distributed activity durations and two types of random rework. A mathematical model is proposed based on a continuous-time Markov decision process (CTMDP) with the objective to minimize the expected project makespan. In order to cope with the curse of dimensionality that comes into play upon solving large-scale instances, we examine a decomposition method that improves the memory management. In addition, we also analyze the effect of random rework on the expected project makespan and decisions, as well as the optimal rework strategy. Finally, a computational experiment with randomly generated project instances as well as with instances from the well-known PSPLIB is set up to validate the effectiveness of the proposed model and procedures.

### 4 - An novel mixed-integer linear programming formulation for the resource-constrained project scheduling problem

*Norbert Trautmann, Tom Rihm*

The resource-constrained project scheduling problem consists in determining start times for a set of precedence-interrelated project activities that require time and scarce resource capacities during execution such that the total project duration is minimized. Besides a large variety of problem-specific solution approaches, various mixed-integer linear programming (MIP) formulations have been proposed in the literature. We present a novel MIP formulation which is based on assignment and sequencing variables. In an experimental performance analysis, it has turned out that the novel formulation outperforms two state-of-the-art models in particular when the resource capacities are very scarce.

## ■ WE-19

Wednesday, 16:30-18:00 - RBM|3302

### Market Entry & Pricing

Stream: Production and Operations Management

Parallel session

Chair: *Mohsen Elhafsi*

#### 1 - Pricing, Lead-time Quotation, Inventory Control and Capacity Setting in a Make-to-order System

*Ata Jalili Marand*

How do the inventory control related costs and uncertainty affect the performance of a manufacturing system quoting a promised delivery time to its time- and price-sensitive customers? We consider this question for a make-to-order system modeled as an M/M/1 queue with an attached inventory. We assume that satisfying each customer's demand requires a unit of a single inventory item. Inventories of the required item, therefore, need to be kept in the system. The inventory is continuously reviewed and at appropriate time epochs purchase orders are placed to replenish the inventory. We deal with this problem under two assumptions: zero and exponentially distributed inventory replenishment lead times. The objective is to maximize the system's long-run average profit by integrating pricing, lead-time quotation, capacity setting and inventory control decisions subject to a service reliability level and inventory control related constraints. We provide the following results. First, we identify a necessary and sufficient condition, in terms of all problem parameters, for the existence of a unique interior solution in the zero replenishment lead time case and characterize the optimal solution. Second, based on the parametric fractional programming, we propose a solution method to solve the problem to the optimality under the assumption of exponentially distributed replenishment lead time. We provide a necessary condition, in terms of all problem parameters, for the existence of an interior solution in this case. Third, we conduct a sensitivity analysis to compare the performance of the system under different circumstances. Our analysis suggests that ignoring the inventory related costs and uncertainty in the decision-making process may lead to complete profit loss.

#### 2 - Disruptive Innovation, Market Entry and Production Flexibility in Oligopoly

*Benoit Chevalier-Roignant*

We model a Cournot oligopoly whereby several innovative firms invest in technology development acquiring the option to enter a new market under stochastic demand. Invested firms have production flexibility to adjust output while market entry gives rise to a coordination problem among rivals. We characterize Markov Perfect Equilibria and derive the option value to invest in general oligopoly. This value is not convex increasing in demand but exhibits "competitive waves" due to rival entry. We further analyze firm asymmetry in technology development and commercialization with economies of scale and examine how firm heterogeneity and market conditions impact on industry structure configuration. A firm with a headstart in technology development or with an advantage in commercialization involving economies of scale will invest when demand is low, while firms with neither advantage may enter only if demand is sufficiently large to accommodate more firms.

#### 3 - Managing an Integrated Production and Inventory System Selling to a Dual Market: Long-Term and Walk-In

*Mohsen Elhafsi, Essia Hamouda ElHafsi*

We consider a manufacturer selling a product through two markets: long-term and walk-in. Walk-in demand materializes according to an independent Poisson process while long-term demand materializes according to a K-stage Erlang distribution. Additionally, demand for the product fluctuates due to varying state of the world conditions evolving according to a finite-state Markov chain. Units are produced ahead of demand, with exponentially distributed times. Sales revenue is collected upon fulfillment of demand. If orders cannot be fulfilled immediately, they are either backordered, in the case of the long-term market, or lost, in the case of the walk-in market. The objective of the manufacturer is to coordinate pricing, production scheduling and inventory allocation, in order to maximize the average expected profit. Due to the different characteristics of the two markets, the long-term market is quoted a single price while the walk-in market is dynamically priced. We formulate the problem as a Markov decision process and characterize the structure of the optimal policy. We show that the optimal policy, in addition to specifying the optimal walk-in market sales

price, is characterized by two state-dependent thresholds: one specifies how to allocate inventory among the two markets and the second specifies how to schedule production. We also study the special cases of static and state of the world dependent walk-in market pricing strategies as well as the case of a spot market where the price is exogenously set. Finally, we conduct numerical experiments to show how the optimal policy is affected by system parameters change.

## ■ WE-20

Wednesday, 16:30-18:00 - RBM|4403

### Supply Chain Planning

Stream: Supply Chain Management

Parallel session

Chair: *Tim Gruchmann*

#### 1 - A Multi-Period Heuristic for Balancing Effort and Plan Quality in Tactical Supply Chain Planning

*Annika Vernbro, Boris Amberg, Stefan Nickel*

In Hierarchical Supply Chain Planning tactical planning is typically executed based on rolling horizons. While optimization models for tactical planning usually address the buckets of a planning horizon simultaneously, common heuristics can be found which plan buckets individually. In practice planning personnel skilled in applying advanced methods is scarce, traceable heuristics may however be the planning method of choice. To allow integrated consideration of the buckets in a horizon, we extend a capacity constrained single-period heuristic to the multi-period-case. Incorporation of key aspects of plan quality is the first guiding design principle, in particular the incorporation of profit maximization as strategic objective, preparation of subsequent planning steps and contained variation in product-resource allocation as a typical operations-specific requirement. The second main principle is consideration of method traceability and intricacy requirements which may be encountered frequently in planning practice. In cooperation with BASF SE this multi-period heuristic has been benchmarked with regard to plan quality against MIP-based planning procedures for Supply Network Planning based on real world data typical for the chemical industry. We give examples how the extent and the nature of the complexities in the supply chain can drastically influence the ability of the multi-period heuristic to appropriately prepare and coordinate subsequent planning steps, in particular scheduling and procurement planning.

#### 2 - Sequential vs. Integrated Solution Approaches for the Combined Manpower Teaming and Routing Problem

*Yulia Anoshkina, Frank Meisel*

In the context of workforce routing and scheduling there are many applications in which workers must perform geographically dispersed tasks, each of which requiring a combination of qualifications. In many such applications, a group of workers is required for performing a task in order to provide all needed qualifications. Examples are found in maintenance operations, the construction sector, health care operations, or consultancies. In this study, we analyze the combined problem of composing worker groups (teams) and routing these teams, under various goals expressing service-, fairness-, and cost-objectives. We develop mathematical optimization models for an integrated solution and a sequential solution of the teaming- and routing-subproblems. The resulting problem shares similarities with the VRP but it also differs in relevant aspects that result from the teaming decision and the qualification requirements. Computational experiments are conducted for identifying the tradeoff of better solution quality and computational effort that comes along with combining the two problems into a single monolithic optimization model. We also analyze the impact of the structure of teams on the different objectives and the efficiency of the provided services.

#### 3 - Managing schedule instability in automotive supply networks: insights from an industry case

*Tim Gruchmann*

Within automotive supply chains schedule instability leads to inefficiencies at production processes of 1st tier suppliers and bears the risk of supply disruptions. Due to the market power of the OEM, 1st tier suppliers are not always able to influence the scheduling behavior of their customers. Accordingly, they need to find an efficient way to protect their production against short-term demand variations. The placement of safety stocks, when designed effectively, is generally seen as a

probate instrument to reach a higher service level. Taking into consideration the scheduling behavior of the customer, safety stocks can be dimensioned more precisely. This paper presents an approach to setup safety stocks calculated on the OEM's forecast reliability. Moreover, this approach is applied to an industry case. By applying the approach to company data, relevant schedule instability related insights are obtained.

## ■ WE-21

Wednesday, 16:30-18:00 - RBM|4404

### Flight Systems

Stream: OR in Engineering  
Parallel session

Chair: Michael Hartisch

#### 1 - An NLP Model for Free-flight Trajectory Planning

Liana Amaya Moreno, Armin Fügenschuh, Anton Kaier, Swen Schlobach

Free-flight emerged as a dynamic alternative to the traditional network approach of Flight Trajectory Planning. Free-flight trajectories are not aligned to an Air Travel Network (ATN), instead, the full 4D space (3D+time) is used for the computation of fuel-efficient trajectories that minimize the travel costs. From a computational point of view, the challenge is to find trajectories, composed of adjacent segments connecting two points (on the earth's surface), that avoid head-winds and benefit from tail-winds. The wind field usually differs in various flight levels (altitudes), therefore the speed of the aircraft and a flight altitude must be assigned to the segments composing the trajectory so the fuel consumption during the flight time is minimized. Moreover, a time constraint is always enforced in order not to incur extra costs due to early or late arrival. This problem is computationally difficult, therefore it is solved in practice, in two subsequent stages: a horizontal phase, in which the segments of a 2D trajectory are computed, and then a vertical phase, in which different altitudes are assigned to the segments. We propose a nonlinear programming model for the computation of Free-flight trajectories. This model requires continuous formulations of the problem's input data such as the fuel consumption and the weather data, hence approximation techniques are required. We integrate the formulation of these approximations into our NLP model using AMPL as modelling language along with the solvers SNOPT, KNITRO and MINOS. We present numerical results on test instances using real-world data provided by our project partner Lufthansa Systems AG and compare the resulting trajectories in terms of the fuel consumption, the trajectories themselves, and the computation times.

#### 2 - Quantified Programming applied to Airplane Scheduling

Michael Hartisch, Simon Gnad

Quantified Mixed Integer Programs (QMIPs) are Mixed Integer Programs (MIPs) with variables being either existentially or universally quantified. They are closely linked to two-person zero-sum games and can be used to model problems under uncertainty. We investigate the matching of airplanes to a finite set of time windows with a maximum number of assigned planes per window. Planes usually have a given time span in which they are expected to arrive at the destination airport. Those time spans may alter due to unforeseen events. The optimization goal is to find a good initial matching such that in the worst case of disturbed arrival times the costs of replanning are minimized. For each plane universally quantified variables are introduced to model the possible alterations of their arrival time. It is extremely important to model the possible disturbances thoroughly: Allowing extreme disturbances may result in an unpractical initial plan, whereas considering only marginal changes will result in a non-robust plan regarding realistic deviations. We present a QMIP model providing the intended optimization goal and present modeling techniques to restrict the universal variables. Further, we show that solving QMIPs using a specialized solver can be beneficial compared to building the deterministic equivalent program and solving the resulting MIP.

#### 3 - Co-allocation of communication messages in an integrated modular avionic system

Elina Rönnberg

Electronics in an aircraft is called avionics and nowadays the majority of the avionics industry uses an integrated architecture called Integrated Modular Avionics (IMA) where applications share hardware resources on a common avionic platform. In such architectures it is vital to prevent faults from propagating between different aircraft functions and one component used to ensure this is pre-runtime scheduling of the tasks and the communication in the system.

In the IMA-system considered in this paper the nodes communicate over a switched Ethernet where communication messages are assigned to and sent in discrete time slots in which the full bandwidth is available. To send a communication message also involves the execution of a set of tasks, both on a module in a sending node and on a module in a receiving node. The execution requirement (duration) of such tasks constitutes of a fixed part for sending a message and a message specific part for the content of the message. To co-allocate messages in a slot means that these messages are treated as a single message and that the tasks involved share the fixed part of the execution requirements. For this reason, co-allocation of messages induces capacity savings at the involved modules.

This paper extends a previous model for pre-runtime scheduling of an IMA-system to facilitate the co-allocation of communication messages. The model is integrated in a constraint generation procedure used for solving large-scale instances of practical relevance and we show some preliminary computational results related to co-allocation of messages.

## ■ WE-22

Wednesday, 16:30-18:00 - HFB|A

### MCDM 2: Multi-Criteria Optimization and Uncertainty

Stream: Decision Theory and Multiple Criteria Decision Making

Parallel session

Chair: Stefan Ruzika

#### 1 - Risk aversion of veto functions in multi-attribute utility theory based preference models

Andrej Bregar

Multi-attribute utility theory has been recently extended with the concept of veto function, which has been adopted from the outranking approach, and models full or partial non-compensation of unsatisfactory preferences. In this research, forms and properties of the veto function are studied, particularly with respect to risk aversion. Outcomes of risk averse, risk seeking and risk neutral veto functions are analysed and compared for additive and multiplicative aggregation models, and with regard to the decision-making problematics of choice, ranking and sorting. Risk aversion of veto functions is also correlated with risk aversion of utility functions, which are aggregated in the same multi-attribute model and exhibit common complementary preference structures of the decision-maker. The aims of the study are to assess the influence of risk aversion on the decision, to identify possible anomalies in preference structures and outcomes, to determine the suitability of different risk aversion formats and intensities for various problem settings, and to derive key characteristics. The study is based on a simulation experiment. The experimental model considers several evaluation factors, such as validity of results, robustness, ability to efficiently discriminate alternatives, richness of output data, extremeness of results, consistency and relevance of judgements, and psychophysical applicability.

#### 2 - Scalarizations for multi-objective combinatorial problems with cardinality-constrained uncertainty

Lisa Thom, Marie Schmidt, Anita Schöbel

Two of the main difficulties in applying optimization techniques to real-world problems are that several (conflicting) objectives may exist and that parameters may not be known exactly in advance. Multi-objective robust optimization tackles these difficulties by combining concepts and methods of two fields: In multi-objective optimization several objectives are optimized simultaneously by choosing solutions that cannot be improved in one objective without worsening it in another objective. To find such solutions one often uses scalarization methods, where the vector-valued objective function is replaced with

a scalar function. Robust optimization hedges against (all) possible parameter values, e.g., by assuming the worst case for each solution (min-max robustness). When solving robust optimization problems the definition of robust solution and the considered uncertainty set play an important role. In the popular concept of cardinality-constrained uncertainty only a bounded number of parameters differs from their minimal value. In this talk, we introduce an extension of cardinality-constrained uncertainty to multi-objective optimization. Further, we present two scalarization methods for multi-objective min-max robust problems, the min-max-min and min-max-max scalarization. We then apply these scalarization methods to multi-objective combinatorial optimization problems with cardinality-constrained uncertainty. We develop MILP-formulations for the resulting problems and investigate their complexity for particular combinatorial problems.

### 3 - A General Approximation Algorithm Applied to Biobjective Mixed Integer Programming Problems

*Stefan Ruzika, Xavier Gandibleux, Pascal Halffmann, Flavien Lucas*

There exist several approaches for approximating general multiobjective minimization problems (see e.g. the work of Papadimitriou and Yannakakis or the work of Glaßer et al.). The output of these algorithms is a set of feasible solutions which constitutes a  $(\alpha, \beta)$ -approximation of the efficient set, i.e., for every efficient solution there exists an approximating solution which dominates this efficient solution up to a factor of  $\alpha$  in the first objective and up to factor of  $\beta$  in the second. The specific values of  $\alpha$  and  $\beta$  depend on the algorithm used. In this talk, we will present the theory of a new approximation algorithm. This algorithm relies on iteratively solving weighted-sum scalarization problems for a certain set of weights. We prove correctness, the approximation quality and a bound on the running time of the algorithm. Moreover, we report on some ongoing work which is concerned with studying how this algorithm (which is mainly motivated by theoretical considerations) can be applied to a difficult class of problems, that is biobjective mixed integer programming problems.

## ■ WE-23

Wednesday, 16:30-18:00 - HFB|B

### Opinion Formation (i)

Stream: Game Theory and Experimental Economics  
*Parallel session*

Chair: *Martin Hoefler*

#### 1 - Opinion Formation Games in Social Networks

*Diodato Ferraioli*

In a discrete preference game, each agent is equipped with an internal belief and declares her preference from a discrete set of alternatives. The payoff of an agent depends on whether the declared preference agrees with the belief of the agent and on the coordination with the preferences declared by the neighbors of the agent in the underlying social network. These games have been used to model the formation of opinions and the adoption of innovations in social networks.

In this talk, we survey recent results about the Price of Anarchy and on the Price of Stability of discrete preference games and the rate of convergence of (noisy) best-response to equilibria. Finally, we use these games to highlight the extent at which social and time pressure can alter the choices taken on a social network.

The talk is based on a joint work with Vincenzo Auletta, Ioannis Caragiannis, Clemente Galdi, Paul W. Goldberg, Giuseppe Persiano, and Carmine Ventre.

#### 2 - Opinion Formation in a Metric Space and Dynamic Social Influences

*Angelo Fanelli*

We consider opinion formation games in which the strategy set of the players is endowed with a distance function which determines a notion of "similarity" among strategies. A player's payoff is determined by two components: the distance from her chosen strategy to her preferred strategy (innate belief) and the weighted average of the distances from her chosen strategy to the strategies chosen by her network neighbours, where the weights denote the strength of the neighbours' influence.

The players' stubbornness is the scaling factor used to counterbalance the two contributions to the players' payoff. We derive tight upper and lower bounds on the efficiency of Nash equilibria as functions of the players' stubbornness. Differently from the previous setting, where the social influences are assumed to be static, we also present simple opinion formation games with dynamic social influences, where opinion formation and social relationships co-evolve in a cross-influencing manner. We show that these games always admit an ordinal potential, and so, pure Nash equilibria, and we design a polynomial time algorithm for computing the set of all pure Nash equilibria and the set of all social optima of a given game. Also in this case we present bounds on the efficiency of Nash equilibria as functions of the players' stubbornness.

### 3 - Opinion Formation with Aggregation and Negative Influence

*Martin Hoefler*

We study continuous opinion formation games with aggregation aspects. In many domains, expressed opinions of people are not only affected by local interaction and personal beliefs, but also by influences that stem from global properties of the opinions present in the society. To capture the interplay of such global and local effects, we propose a model of opinion formation games with aggregation, where we concentrate on the average public opinion as a natural way to represent a global trend in the society. While the average alone does not have good strategic properties as an aggregation rule, we show that with a limited influence of the average public opinion, the good properties of opinion formation models are preserved.

More formally, we show that a unique equilibrium exists in average-oriented opinion formation games. Simultaneous best-response dynamics converge to within distance  $\epsilon$  of equilibrium in  $O(n^2 \ln(n/\epsilon))$  rounds, even in a model with outdated information on the average public opinion. For the price of anarchy we show a small bound of  $9/8 + o(1)$ , almost matching the tight bound for games without aggregation. Moreover, we prove some of the results in the context of a general class of opinion formation games with negative influences, and we extend our results to cases where expressed opinions must come from a restricted domain.

## ■ WE-24

Wednesday, 16:30-18:00 - HFB|C

### Multiobjective Linear Programming and Global Optimization

Stream: Control Theory and Continuous Optimization  
*Parallel session*

Chair: *Andreas Löhne*

#### 1 - Algorithm for solving bilevel optimization problems being polyhedral on the lower level

*Alexandra Rittmann*

This talk presents an algorithm for solving bilevel optimization problems (BLP) being polyhedral on the lower level. Bilevel optimization problems are mathematical optimization problems, where a part of the constraints of the so-called upper level are determined by the solutions of a second optimization problem, the lower level problem. In general this leads to non-convex constraints on the upper level.

Fulop [1993] has shown, that linear bilevel optimization problems can be solved by optimizing the upper level objective function over the set of Pareto-optimal extremal points of a corresponding multiple objective linear program (MOLP). By picking up this idea we propose an algorithm which is an extension of Benson's outer approximation algorithm for solving linear vector optimization problems to compute the feasible set of (BLP). Furthermore the algorithm uses branch and cut techniques to construct hyperplanes which are added to the inequality representation of the feasible set of (MOLP) in order to avoid the calculation of all feasible points of (BLP).

## 2 - Bendsolve tools - polyhedral calculus with Matlab/Octave

Andreas Löhne, Benjamin Weißing, Daniel Ciripoi

We present a tool box to treat the following problem classes with Matlab and Octave: 1. Calculus of convex polyhedra and polyhedral convex functions, 2. Multiobjective linear programming, 3. Global optimization.

Among other operations, one can compute the Minkowski sum, intersection and the convex hull of the union of two convex polyhedra; moreover, the polar, an H-representation and a V-representation of a convex polyhedron. The tool box also covers subset testing. Given two polyhedral convex functions, we provide commands to compute, for instance, their infimal convolution, pointwise maximum or lower convex envelope. Also, one can compute the conjugate of a polyhedral convex function. The global optimization part covers problem classes like minimizing a quasi-concave objective function under linear constraints, minimizing the difference of two polyhedral convex functions and others.

The toolbox is based on the vector linear programming solver Bendsolve and a recent result saying that polyhedral projection is equivalent to multiobjective linear programming.

## 3 - Decomposition-based Inner- and Outer-Refinement Algorithms for Global Optimization without Branching

Ivo Nowak

Traditional deterministic global optimization methods are often based on a branch-and-bound tree, which may grow rapidly, preventing the method to find a good solution. Motivated by column generation methods for solving transport scheduling problems with over 100 million variables, we present a new deterministic global optimization approach, called Decomposition-based Inner- and Outer-Refinement (DIOR), which is not based on branch-and-bound.

DIOR can be applied to general modular and/or sparse optimization models. It is based on a block-separable reformulation of the model into sub-models, which can be solved in parallel. In the first phase, the algorithm generates inner- and outer-approximations using column generation. In the second phase, it refines a nonconvex outer approximation based on a convex-concave reformulation of sub-problems. Local solutions are computed by a decomposition-based alternating direction method. We present preliminary numerical results with Decogo, a new DIOR-based MINLP solver implemented in Python and Pyomo.

## WE-25

Wednesday, 16:30-18:00 - HFB|D

### Open-source and Computation Time in Energy Models

Stream: Energy and Environment  
Parallel session

Chair: Dirk Hladik

Chair: Philipp Hauser

#### 1 - A Large-scale Spatial Open-source Electricity Market Model Using the Julia Language

Jens Weibezahn, Mario Kendziorski, Jan Zepter

In this paper, we develop a fully open-source bottom-up electricity sector model with high spatial resolution using the Julia programming environment, including a complete description of source code and data set. This large-scale model of the German electricity market includes both generation dispatch in the spot market as well as the physical transmission network, minimizing total system costs for the year 2015 in a linear approach. It simulates the market on an hourly basis, taking into account demand, renewables infeed, and storages, exchanges with neighbouring countries, as well as combined heat and power with a detailed representation of major district heating systems and an extensive graphical representation of results.

Following an open-source approach, model code and used data set are being made fully publicly accessible and open-source solvers like GLPK and Ipopt are used. The model is hence being benchmarked regarding runtime of building and solving against an extended version

of the ELMOD-DE model in GAMS as a commercial algebraic modeling language and against Gurobi and CPLEX as commercial solvers. With this paper we want to show the power and abilities as well as the beauty of open-source modelling systems, available free of charge for analyses and studies to everyone even in less developed countries with fewer financial possibilities. In addition, the model represents a framework for further extensions and usage towards the open-source modeling of other electricity markets.

#### 2 - Reducing computing times in optimizing energy system models- challenges and opportunities

Felix Cebulla, Karl-Kien Cao, Manuel Wetzel, Frederik Fiand, Hans Christian Gils

Energy systems based on renewable resources are characterized by a high number of decentralized components as well as by an increasing importance of storage, grid, and demand response. Energy system models reflect this growing complexity by combining a comprehensive representation of energy sectors and technologies with a high spatial and temporal resolution. However, such high level of detail is typically associated with long solving times of the models. The reduction of the latter is urgently required and the need for guidelines for a reasonable balance between degree of detail and solution time is pressing. The BEAM-ME project addresses these questions using improved modelling approaches and more efficient formulations of energy systems models. The German Aerospace Center is the principal investigator on the modelling side, while the project gathers various partners with complementary expertise in the fields of optimization algorithms, high performance computing, and application development. This talk provides an overview and evaluation of conceptual and technical strategies identified so far to reduce the model solution time of the REMix energy system model. Moreover, an insight in the implementation and assessment of selected speed-up strategies is provided. Finally, conclusions from the first project results are drawn and an outlook on the subsequent works is given.

## WE-26

Wednesday, 16:30-18:00 - HFB|Senat

### Managerial Economics

Stream: Game Theory and Experimental Economics  
Parallel session

Chair: Rainer Kleber

#### 1 - Inspection strategies and risk self-assessment - an extension of the classical inspection game

Jan Trockel, Benjamin Florian Siggelkow

In this paper we set forth the conditions governing the probability of the reduction of intensive auditor's control and discuss how this decrease proves beneficial for the organization assigning the audit. We also show that the unique roles of risk management and internal audit decrease the level of risk in the organization. Firstly, the classical inspection game is adapted to an approach of internal auditing with one auditee and one internal auditor. Secondly, the number of auditees is increased to two auditees. Thirdly, we extend the classical inspection game by risk self-assessment of the auditees, that we define as the risk management game. It can be shown that the control probability in the three-person approach is lower than in the classical inspection game. In the auditee-auditee-auditor approach, the auditees' probability of correct behavior increases as well and thus leads to better risk management for the organization.

#### 2 - Audit Strategies in the Presence of Evasion Capabilities: a Mechanism Design Approach

Francis de Vericourt

In this work, we provide managerial insights on how to uncover an adverse issue that may occur in organizations with the capability to evade detection. To that end, we formalize the problem of designing efficient auditing and remediation strategies as a dynamic mechanism design problem. In this set-up, a principal seeks to uncover and remedy an issue that occurs to an agent at a random point in time, and which harms the principal if not addressed promptly. This occurrence is the agent's private information. Further, the agent can exert effort to render the principal's audits ineffective at discovering the issue. We fully characterize, in closed form, the corresponding optimal policy, which can be implemented as a dynamic remediation cost-sharing mechanism with



cyclic audits. We show that the strength of the agent's evasion capability changes the nature of the audit policy. When the effort cost is high (i.e., the evasion capability is weak), the principal runs the audit according to a pre-determined schedule. However, when the effort cost is low (i.e. the evasion capability is strong), the audit schedule becomes random. Further, as the effort cost increases and the evasion capability becomes more limited, the principal audits the agent more frequently, which overall results in higher audit costs.

### **3 - On the Robustness of the Consumer Homogeneity Assumption with Respect to the Discount Factor for Remanufactured Products**

*Rainer Kleber, Marc Reimann, Gilvan C. Souza, Weihua Zhang*

The strategic closed-loop supply chains (CLSCs) literature makes the assumption that a consumer's willingness-to-pay (wtp) for a remanufactured product is a fraction of his/her wtp for the corresponding new product, and this fraction, called discount factor, is assumed to be constant among consumers. Recent empirical research challenges this assumption, by showing that there is considerable variability in discount factors among consumers. This paper considers a complex model in the CLSC literature: strategic remanufacturing under quality choice, and compares its solution under constant discount factors with the solution that assumes a probability distribution for the discount factors (which is analytically intractable and must be obtained numerically). We consider quality choice and remanufacturing for both monopoly and competitive cases. Overall, we find remarkable consistency between the results of the constant and variable discount factor models. Thus, we make a convincing argument that the constant discount factor assumption is robust and can be used due to its tractability.

## Thursday, 9:00-10:30

### ■ TA-01

Thursday, 9:00-10:30 - WGS|101

#### Risk Aversion in Stochastic Programming

Stream: Optimization under Uncertainty

Parallel session

Chair: Matthias Claus

##### 1 - Risk averse scheduling with scenarios

*Mikita Hradovich, Adam Kasperski, Pawel Zielinski*

We are given a set of jobs which must be executed on some machines. For each job a set of parameters, such as a processing time, a due date or a weight can be specified. In the classic deterministic case the values of these parameters are known precisely and we seek a schedule which minimizes a given cost function. In practical applications, the exact values of the parameters are rarely known in advance. We can model this uncertainty by introducing a scenario set, containing a set of possible parameter realizations. One popular method of defining scenario set is the discrete uncertainty representation, under which a finite set of joint realizations of the parameters is specified. We assume that a probability distribution in the scenario set is known. The cost of a given schedule is then a discrete random variable with known probability distribution. In order to compute a solution the popular risk criteria, such as the value at risk and the conditional value at risk, can be used. These criteria allow us to establish a link between the very conservative maximum criterion, typically used in robust optimization, and the expectation, commonly used in the stochastic approach. Using them we can take a degree of risk aversion of decision maker into account. In this paper we consider various scheduling models with a specified scenario set and the risk criteria for choosing a solution. We show some new negative and positive complexity results for them.

##### 2 - On stability of stochastic bilevel programs with risk aversion

*Matthias Claus*

Two-stage stochastic programs and 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 desirable analytical properties. The talk focuses on mean risk formulations of stochastic bilevel programs where the lower level problem is quadratic. Based on a growth condition, weak continuity of the objective function with respect to perturbations of the underlying measure is derived. Implications regarding stability for a comprehensive class of risk averse models are pointed out.

### ■ TA-02

Thursday, 9:00-10:30 - WGS|102

#### Nonlinear Programming Solvers and Specialized Interfaces

Stream: Software Applications and Modelling Systems

Parallel session

Chair: Renke Kuhlmann

##### 1 - WORHP Zen: A Parametric Sensitivity Analysis for the Nonlinear Programming Solver WORHP

*Renke Kuhlmann, Sören Geffken, Christof Büskens*

Nonlinear optimization problems that arise in real-world applications usually depend on parameter data. Parametric sensitivity analysis is concerned with the effects on the optimal solution caused by parameter changes. The calculated sensitivities are of high interest because they improve the understanding of the optimal solution and allow the formulation of real-time capable update algorithms. We present WORHP Zen, a sensitivity analysis module for the nonlinear programming solver WORHP that is capable of the following: (i) Efficient calculation of parametric sensitivities using an existing factorization; (ii)

efficient sparse storage of these derivatives, and (iii) real-time updates to calculate an approximated solution of a perturbed optimization problem. Finally, an application of WORHP Zen in the context of parameter identification is presented. Besides the fitting of the parameters, a somehow contrary goal is to minimize the curvature of the resulting parameter maps. Here, the parametric perturbation is the weight for the curvature component of the objective function. Choosing a suitable weight can be a difficult task for the user. The computed sensitivity fields greatly increase the understanding of the effects of this perturbation to the resulting model.

##### 2 - Efficient Computation of Pareto Frontiers with the Multi-Objective Interface of WORHP

*Arne Berger, Sören Geffken, Christof Büskens*

In order to solve non-linear problems which consist of multiple objectives, one usually solves scalarized subproblems. One method is the Pascoletti-Serafini scalarization. The solutions of these subproblems represent samples of the so called Pareto-Front. Challenges are for example the minimization of computational effort and the generation of an evenly distributed set of samples. Parametric sensitivity analysis can be used to tackle both of these problems. It can be used for: (i) Calculating good initial guesses based on the solution of scalarized problems which are "near by". (ii) Implementation of an adaptive variation of hyper-parameters in order to improve the distribution of sample points on the Pareto-Front.

This talk will present how the information gained by parametric sensitivity analysis is exploited within the multi-objective interface of the NLP solver WORHP. Numerical results will be demonstrated using an example from parameter identification.

##### 3 - On the performance of NLP solvers within global MINLP solvers

*Benjamin Müller, Renke Kuhlmann, Stefan Vigerske*

Solving mixed-integer nonlinear programs (MINLPs) to global optimality efficiently requires fast solvers for continuous sub-problems. These appear in, e.g., primal heuristics, convex relaxations, and bound tightening methods. Two of the best performing algorithms for these sub-problems are Sequential Quadratic Programming (SQP) and Interior Point Methods.

In this talk we present the impact of different SQP and Interior Point implementations on important MINLP solver components that solve a sequence of similar NLPs. We use the constraint integer programming framework SCIP for our computational studies on instances of the minplibtwo instance library.

### ■ TA-03

Thursday, 9:00-10:30 - WGS|103

#### Vehicle Routing - Column Generation

Stream: Logistics and Freight Transportation

Parallel session

Chair: Stefan Irnich

##### 1 - Branch-and-Price-and-Cut for the Periodic Vehicle Routing Problem with Different Schedule Structures

*Ann-Kathrin Rothenbächer*

This paper deals with the periodic vehicle routing problem with time windows (PVRPTW). A set of customers requires one or several visits during a planning horizon of several periods. Given schedules per customer determine the offered visit period combinations. In previous work, each customer usually was assumed to require a specific visit frequency and to offer all corresponding schedules with regular intervals between the visits. In this paper, we permit all kind of schedule structures and the choice of a higher service frequency. We present an exact branch-and-price-and-cut algorithm for the classical PVRPTW and its variant with more flexible schedules. The pricing problem is based on two new networks and solved with a labeling algorithm, which uses several known acceleration techniques as the NG relaxation and dynamic half-way points within bidirectional labeling. For the case of periodic schedules, we apply some ideas to effectively deal with the symmetry. Computational tests on benchmark instances for the PVRPTW show the effectiveness of our algorithm. Furthermore, extensive comparisons analyze the different schedule structures.

## 2 - Bidirectional Labeling in Column-Generation Algorithms for Pickup and Delivery Problems

Timo Gschwind, Stefan Irnich, Ann-Kathrin Rothenbacher, Christian Tilk

For the exact solution of many types of vehicle routing problems, column-generation based algorithms have become predominant. The column-generation subproblems are then variants of the shortest-path problem with resource constraints which can be solved well with dynamic programming labeling algorithms. For vehicle routing problems with a pickup-and-delivery structure, the strongest known dominance between two labels requires the delivery triangle inequality (DTI) for reduced costs to hold. When the direction of labeling is altered from forward labeling to backward labeling, the DTI requirement becomes the pickup triangle inequality (PTI). DTI and PTI cannot be guaranteed at the same time. The consequence seemed to be that bidirectional labeling, one of the most successful acceleration techniques developed over the last years, cannot be effectively applied to pickup and delivery problems. In this paper, we show that bidirectional labeling with the strongest dominance rules in forward as well as backward direction is possible and computationally beneficial. A full-fledged branch-and-price-and-cut algorithm is tested on the pickup and delivery problem with time windows.

## 3 - Nested column generation for a rich vehicle routing problem

Christian Tilk, Stefan Irnich

In this talk, we consider an extension of the vehicle routing problem with time windows in which additionally minimum and maximum delivery quantities for each customer are given and a customer-dependent profit is paid for each demand unit delivered. Additionally, synchronization between some pairs of customers is required. We call the problem vehicle routing problem with time windows, soft demand and customer synchronization (VRPTWSDSC). We solve the problem with a branch-and-price algorithm. The corresponding subproblem is an elementary shortest path problem with resource constraints (ESPPRC) in which a tradeoff between cost and time as well as a tradeoff between load and time exists. For the exact solution of many ESPPRC variants, dynamic programming based labeling algorithms are predominant. When using a labeling algorithm to solve the subproblem of the VRPTWSDSC, the handling of the tradeoffs necessitate the usage of two interdependent tradeoff curves resulting in a weak dominance criterion such that the algorithm is almost a pure enumeration. Therefore, we solve also the subproblem with branch-and-price. The arising sub-subproblem asks for negative reduced-cost paths that are feasible with respect to time windows, minimum delivery quantities and precedences arising from the synchronization constraints. The sub-master problem then determines the visiting time and the delivery quantity for each customer. This results in a multi-layer branch-and-price algorithm. Therein, some data generated in the upper layers can be useful in the lower layers and vice versa. We analyze different variants of the algorithm to enable, e.g., the exchange of columns between the different layers.

layer separately and then conduct ways to combine the layers into a multiplex. We validate both models with the European Air Transportation Network and discuss the results. The first method strikes with its simplicity however it neglects the interconnections between the layers. The second, more complex method benefits from the influence on the layer relationships.

## 2 - The Free Route Flight Planning Problem on Airway Networks

Adam Schienle, Marco Blanco, Ralf Borndörfer, Nam Dung Hoang

The Flight Planning Problem (FPP) deals with finding a minimum cost flight trajectory subject to initial conditions such as departure and destination airport, fuel cost and weather conditions. Traditionally, an aircraft's horizontal route is restricted to the Airway Network, a directed graph. Time dependent weather conditions allow us to model the FPP as a Time-Dependent Shortest Path Problem. Since the Airway Network is prevalent almost everywhere on earth, this structure renders combinatorial shortest path algorithms, such as Dijkstra's algorithm and algorithms derived from it, a natural choice for solving FPP. Wishing to give the users of the Airway Network more freedom in planning their routes, together with easing congestion in parts of the network, gives rise to an increasing number of Free Route areas. Essentially, these are regions where there is no network defined at all, or where it is allowed to travel directly between any two points of the network, thus corresponding to cliques in the directed graph. This leads to the Free Route Flight Planning Problem, whose altered network structure impacts the performance of combinatorial shortest path algorithms. In the talk, we shall discuss different algorithmic approaches to solve the Free Route Flight Planning Problem.

## 3 - Cost Minimal Aircraft Trajectories on Airway Networks

Pedro Maristany de las Casas, Marco Blanco, Ralf Borndörfer, Nam Dung Hoang

Given the departure and destination airports, the Flight Planning Problem (FPP) seeks to find cost minimal flight trajectories for commercial aircraft along the Airway Network (A.N.), which is modeled as a digraph.

In a static setting of the FPP, where time dependent components are neglected, the two main cost components for such a trajectory are fuel and overflight costs (OFC). While fuel costs can be defined as costs on the arcs of the A.N., there are many airspaces, such as the European ones, where OFCs do not depend on the chosen route within the airspace, but instead are linearly dependent on the great-circle distance between entry and exit nodes for this airspace.

In this talk we will discuss the Shortest Path Problem with Crossing Costs (SPPCC), a generalization of the known Shortest Path Problem (SPP), which translates the described properties into a combinatorial problem. Crossing Costs are the general term used to refer to overflight costs.

The talk will begin with a brief analysis of the complexity of the SPPCC. The polynomial case described above can be solved using an algorithm called Two Layer Dijkstra (2LD), which yields a non satisfying runtime in practice.

Thus, during the talk, we will mainly focus on the analysis of different methods that can be used to distribute the exact OFCs over the arcs of the corresponding region. Finding good such methods allows us to reduce SPPCC instances to SPP instances, thus being able to approximate a solution to the original problem extremely fast. This reduction does not only perform well concerning the runtime of the algorithm ( $\times 708$  faster in average than using the 2LD), but also concerning the quality of the approximated solutions: they differ by 0.09% from the optimal ones.

## ■ TA-04

Thursday, 9:00-10:30 - WGS|104

### Graphs in Air Transportation

Stream: Graphs and Networks

Parallel session

Chair: Pedro Maristany de las Casas

#### 1 - Synthetic Models for Multi-Layered Networks

Marzena Fügenschuh, Raluca Gera, Mitchell Heaton, Tobias Lory

Air transportation networks are known to have a multiplex structure. These networks evolve independently by carriers based on economic and political factors as well as interaction between one another. Creating synthetic models for air transportation networks provides a tool towards a deeper understanding of their structure and development. In particular, the multi-layer structure is hard to be imitated. We present two models for building multiplex networks following two different approaches. In the first model we create the multiplex using a modified preferential attachment and simultaneously assign the edges to the layers. In the second approach we mimic first the structure of each

## ■ TA-05

Thursday, 9:00-10:30 - WGS|104a

### Matching, Coloring, and Ordering (i)

Stream: Discrete and Integer Optimization

Parallel session

Chair: Michael Juenger

### 1 - Robust Recoverable Matchings on a Budget

Moritz Mühlenthaler, Viktor Bindewald

We investigate the complexity of making matchings in a graph robust against the deletion of edges. The robustification happens either before fixing a particular matching or afterwards. In both settings there are budget restrictions for deleting edges and repairing a matching. In the former setting, the task has recently been proved to be NP-hard. We show that for a suitable restriction of the input graphs the problem becomes tractable. To the best of our knowledge, the second setting has not been considered before and we present a number of complexity results. They indicate that making existing infrastructure robust is as hard as designing robust infrastructure.

### 2 - A New Integer Linear Programming Model for the Vertex Coloring Problem

Adalat Jabrayilov

The vertex coloring problem asks for the minimum number of colors that can be assigned to the vertices of a given graph such that for all vertices  $v$  the color of  $v$  is different from the color of any of its neighbors. The problem is NP-hard. Here, we introduce a new integer linear programming formulation which is based on partial orderings. It has the advantage that it is as simple to work with as the "classical assignment formulation", since it can be fed directly into a standard integer linear programming solver. We evaluate our new model using Gurobi and show that our new simple approach is a good alternative to the best state-of-the-art approaches for the vertex coloring problem. We also compared our formulation with other simple formulations like the "classical assignment formulation" and "representative formulation" on a large set of benchmark graphs as well as randomly generated graphs. The evaluation shows that our new model dominates both formulations for sparse graphs, while the representative formulation is best for dense graphs.

### 3 - Mixed-Integer Programming Models for Multiprocessor Scheduling with Communication Delays

Sven Mallach

We revise existing and introduce new mixed-integer programming models for the Multiprocessor Scheduling Problem with Communication Delays and the objective to minimize the makespan. Especially, we reveal that the feasible region of almost all existing formulations contains redundant solutions and formulate new constraints in order to exclude these. As a result and by exploiting further structural properties, the models are improved in their strength and, at the same time, in terms of their size and modeling complexity. This inevitably leads to new more compact formulations which are then experimentally compared with each other and with further formulations from the literature.

## ■ TA-06

Thursday, 9:00-10:30 - WGS|105

### Routing

Stream: Graphs and Networks  
Parallel session

Chair: Jörn Schrieber

#### 1 - Decomposition of edge-coloured Eulerian graphs (with an application in vehicle scheduling)

Hanno Schülldorf

From an application in rail freight vehicle scheduling, we derive a new graph theoretical problem: given an Eulerian graph with coloured edges, is there a non-trivial decomposition into cycles such that all edges with the same colour are in the same cycle? After some remarks on preprocessing we will discuss heuristic ideas and show first results. We will conclude with some open questions of particular interest related to this problem.

#### 2 - Subtours - Useful Helpers to Solve Travelling Salesman Problems

Cornelius Rüter, Katherina Meißner, Klaus Ambrosi

The Travelling Salesman Problem (TSP) is a combinatorial optimization problem to which the optimal solution cannot be found in a reasonable short time for large instances. In this paper we are going to describe a new heuristic, which, according to our research, has not been discussed in scientific literature yet.

Our heuristic starts with an infeasible solution of a TSP that includes subtours. Such an infeasible solution is exact and can be found through integer programming. It then tries to merge these subtours fast and cost-efficiently, so that the increase in cost in every merging step is as small as possible. The basic idea is to generate a problem-based metric to get information on the approximated distances between the subtours. As a result, we are able to estimate which subtours should be merged. In a second step, we will upgrade the basic idea to improve the subtour-selection. Finally, we will improve the subtour joining by developing different ideas for minimal cost increase during the merging process.

We will present our findings in the form of a benchmark-study, which compares 3-Opt with our heuristic as well as the different selection methods within our heuristic, applying the well-known data-set USA13509.

### 3 - Cost-Dependent Clustering: A General Multiscale Approach to Optimal Transport

Jörn Schrieber, Anita Schöbel, Dominic Schuhmacher

Optimal transport is a classical problem with a variety of modern applications. The Wasserstein or earth mover's distance obtained from it is a useful tool in computer science, engineering and statistics. However, large optimal transport problems are still computationally challenging.

The recent past has seen the advent of a variety of multiscale methods to tackle large discrete optimal transport problems, where solutions to coarser versions of the problem are used to initialize the finer problem. While many different algorithms have been proposed to be used with a multiscale scheme, the scaled instances themselves are mostly generated as simple coarsenings of the original instances.

Cost-dependent clustering is a new approach to construct small-scale approximations of discrete optimal transport instances by coupling points with regard to similar cost vectors. Using the solution to the clustered problem, we derive upper and lower bounds on the optimal value of the original instance. The clustering approach is independent of the structure of the underlying space and can be applied to general cost functions.

## ■ TA-07

Thursday, 9:00-10:30 - WGS|106

### Computational Mixed-Integer Programming 1

Stream: Discrete and Integer Optimization  
Parallel session

Chair: Ambros Gleixner

#### 1 - Exploring the Numerics of Branch-and-Cut for Mixed Integer Linear Optimization

Matthias Miltenberger, Ted Ralphs, Daniel Steffy

We investigate how the numerical properties of the LP relaxations evolve throughout the solution procedure in a solver employing the branch-and-cut algorithm. The long-term goal of this work is to determine whether the effect on the numerical conditioning of the LP relaxations resulting from the branching and cutting operations can be effectively predicted and whether such predictions can be used to make better algorithmic choices. In a first step towards this goal, we discuss here the numerical behavior of an existing solver in order to determine whether our intuitive understanding of this behavior is correct.

#### 2 - Measuring the Impact of Branching Rules for MIP

Gerald Gamrath, Christoph Schubert

Branching rules are an integral component of the branch-and-bound algorithm typically used to solve mixed integer programs and subject to intense research. Different approaches for branching are typically compared based on the solving time as well as the size of the branch-and-bound tree needed to prove optimality. The latter, however, has some flaws when it comes to sophisticated branching rules that do not

only try to take a good branching decision, but have additional side-effects. We propose a new measure for the quality of a branching rule that distinguishes tree size reductions obtained by better branching decisions from those obtained by such side-effects. It is evaluated for common branching rules providing new insights in the importance of strong branching.

### 3 - Compiling MIPLIB 2017: the 6th Mixed-Integer Programming Library

Ambros Gleixner

Since its first release in 1992, MIPLIB has become a standard test set used to compare the performance of mixed-integer linear optimization software and to evaluate the computational performance of newly developed algorithms and solution techniques. It has been a crucial driver for the impressive progress we have seen over the last decades. In this talk we will give an overview of the activities to compile the sixth edition of MIPLIB and present the current status. This work is only possible due to the concerted efforts of many researchers and developers from academic and commercial MIP solver software.

## ■ TA-08

Thursday, 9:00-10:30 - WGS|107

### Data-driven Transportation Analysis

Stream: Traffic, Mobility and Passenger Transportation  
*Parallel session*

Chair: Alexander Immer

#### 1 - Analyzing Temporal Mobility Patterns of Senior and Disabled Passengers in a Multimodal Setting

Büşra Sevinç, Uğur Eliiyi, Selma Gürler

Providing a comfortable public transportation service to its senior and disabled citizens is one of the vital topics for a metropolitan city in order to reach higher liveability rankings. Izmir, the third largest city of Turkey, needs to improve also in that aspect all through its vast multimodal transit network. In view of that, we consider a temporal ridership analysis of senior and disabled passengers, who regularly use a specific intermodal transfer center in Izmir. The active transport modes evaluated for that center are bus, metro and ferry systems. The location-specific boarding data includes immediate connections' info, namely for both previous and subsequent transfer trips if present. The boarding times are analyzed synchronously with scheduled departure or arrival times of the buses, trains or ferries for getting more robust results. The boarding fees of the disabled and senior passengers are waived totally, or partially with respect to age intervals. Therefore, time-stamped ridership statistics might reflect the mobility preferences of those passengers regarding factors such as vehicle types, peak-hour utilization, traffic congestion and accessibility issues. The individual trip patterns of passengers are examined over a four-week period. Apart from the individual trips of a day for a passenger, her trips in consecutive days are also evaluated for drawing preferred route maps and measuring their regular ridership behaviors. In this manner, it is possible to predict the specific requirements of these passengers and accordingly form a solid information base for planning alternative routes or schedules that may ensure higher passenger satisfaction levels.

#### 2 - Joint Travel Mode Detection and Segmentation using Recurrent Neural Networks

Alexander Immer, Florian Stock, Patrick Wagner

Transportation survey data is highly useful for planning and optimizing infrastructure or understanding human mobility behaviour. Smartphones allow the collection of location and sensory data with few or no interaction of study participants. To make use of such data, especially when available in high volume, it is necessary to detect transportation modes and changepoints in between these automatically.

We propose a mode detection and journey segmentation algorithm based on a recurrent neural network with gated recurrent unit (GRU). Previously proposed methods have either neglected the temporal characteristic of such data by classifying time frames individually or used methods that are restricted to a fixed order of temporal dependencies.

In real-world studies, we collected more than 2000 hours of labelled travel data hundreds of different users with various devices. We are

therefore able to train and evaluate our models on one of the largest and most general data sets of such kind. We investigate if treating the data as sequences, i.e. structured objects, leads to superior performance compared to other recently successful approaches.

### 3 - Enhancing option bundling for automotive manufacturers by reducing demand variability

Radu Constantin Popa, Martin Grunow

Premium automotive manufacturers strive to maintain a competitive advantage by offering their customers a wide array of customization possibilities by means of options. The heterogeneity of customer preferences that results from the freedom of choice leads to difficulties in accurately forecasting the demand for options. Automotive manufacturers use the forecasts to plan production and to derive the component demands that are communicated to the suppliers. The uncertainty regarding the accuracy of these requirements and the pressure to cope with component demands changed on a short notice can severely strain the relationship of the automotive manufacturers with the suppliers.

Our work presents a branch and price approach that enhances the design of bundles by minimizing the variability of the demand of the options alongside the maximization of the revenues. We highlight the advantages of simultaneously considering both perspectives compared to traditional option bundling approaches that focus only on improving revenues or profits. We also analyze the impact of input parameters, such as the willingness to pay of customers for individual options or the discounts offered for the acquisition of bundles, on the bundles designed by our approach, as well as the resulting revenues and options demand variability.

## ■ TA-09

Thursday, 9:00-10:30 - WGS|108

### Location Problems

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: Andreas Klöse

#### 1 - Cut generation algorithm for the competitive facility location problem

Andrey Melnikov, Vladimir Beresnev

The paper considers a Stackelberg game where two players sequentially open their facilities with egoistic aims to maximize own profits calculated as income from service customers minus cost of open facilities. Both the set of potential facility locations and the set of customers are assumed to be finite and known for the players. It is assumed that each customer has preferences represented with a linear order on the set of potential locations and utilizes a single facility to satisfy his or her demand. In the model, a player can service a customer only with a facility which is more preferable for the customer than any another player's facility. The problem can be written in terms of bilevel mixed-integer linear programming. A cut generation scheme suggested in the present paper obtains an optimal solution of the model by solving a series of common MIPs derived from the initial bilevel program with an inner goal function excluded (so-called high-point problem). An obtained single-level program is iteratively supplemented with inequalities approximating a feasible region of the bilevel program. The inequalities are taken from an exponential family of valid cuts based on properties of optimal solutions of the inner problem. The idea behind these inequalities is to formulate a sufficient condition of a subset of facilities to contain a facility which is open in optimal Follower's solution. By adding the mentioned inequalities coupled with constraints forcing Follower's variables to take their optimal values for a given values of Leader's variables, the solutions of obtained MIPs converge to the optimal solution of the initial bilevel program. Numerical experiments show that a number of added cuts and, consequently, a number of solved MIPs is relatively small.

#### 2 - Crane selection and location on construction sites

Michael Dienstknecht, Dirk Briskorn

Cranes are a key element on construction sites and are among the most expensive construction equipment. Thus, crane selection and location are an important factor with respect to a construction project's profitability. In this research, a set of pairs of supply and demand areas - modelled as polygons - on a polygonal construction site has to be covered by tower cranes. For covering these pairs, there are different types of tower cranes available, each with specific attributes such as rental cost and working radius. The goal is to find a minimum-cost

selection of cranes and the cranes' locations on-site so that each pair is completely covered by at least one crane. It is shown that for each crane type, we can restrict ourselves to a finite set of candidate crane locations without loss of optimality. Thus, once these candidate locations are generated, the problem of crane selection and location can be modelled as a classic set cover problem. A brief overview on computational results is given, as well.

### 3 - A branch-and-bound algorithm for the capacitated facility location problem with convex production costs

*Andreas Klose*

We consider the capacitated facility location problem (CFLP) with differentiable convex production cost functions. The problem arises in numerous real-world applications as queues in call-centres, server queueing or when production is pushed beyond normal capacity limits. For finding proven optimal solutions, we suggest a branch-and-bound algorithm based on Lagrangian relaxation and subgradient optimization. The algorithm basically extends a similar method for the classical linear cost CFLP to the convex cost case. The method is compared on a large number of test instances to three other exact solution approaches: The use of perspective cuts, a second-order cone (SOC) MIP formulation for the case of quadratic costs, and Benders' decomposition. Our computational results indicate that in many cases the branch-and-bound method is superior to both the perspective cut approach, the SOC MIP, and the application of Benders' decomposition.

## ■ TA-10

Thursday, 9:00-10:30 - WGS|108a

### Polyhedral Methods and Symmetry Exploitation

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *Matthias Walter*

#### 1 - On the Size of Integer Programs with Sparse Constraints or Bounded Coefficients

*Hendrik Lüthen, Christopher Hojny, Marc Pfetsch*

Given a set of integer points and an objective function, one often is interested in formulating the corresponding optimization problem as an integer program. Since there are many such possibilities, we investigate different characteristics, including sparsity and the size of the coefficients of the formulation. We prove lower bounds on the size of integer programs, while limiting these two properties. Furthermore, we investigate conditions for which a general objective function can be handled in a mixed integer program.

#### 2 - Symmetry in Mixed Integer Programs: Refined Orbitopes and Extended Formulations

*Andreas Schmitt, Christopher Hojny, Marc Pfetsch*

We present an approach to handle symmetry in mixed integer programs, based on so-called orbitopes. Consider the graph partitioning or graph coloring problems as examples. Here the variables assigning nodes to parts or colors form a binary matrix with the property that any reordering of the columns leads to another solution of the problem. An orbitope is the convex hull of such binary matrices whose columns are sorted lexicographically non-increasing and can be used to completely handle such column symmetry.

In this talk, we consider the special case in which each column can contain at most  $k-1$  entries. We develop a compact extended formulation for the corresponding polytope. Furthermore, numerical results show the effect of the extended formulation on the LP relaxation.

#### 3 - Parity Polytopes and Binarization

*Matthias Walter, Dominik Ermel*

We consider generalizations of parity polytopes whose variables, in addition to a parity constraint, satisfy certain ordering constraints. More precisely, the variable domain is partitioned into  $k$  contiguous groups, and within each group, we require the  $x$ -components to be nonincreasing. Such constraints are used to break symmetry after replacing an integer variable by a sum of binary variables, so-called binarization. We provide extended formulations for such polytopes, derive a complete outer description, and present a separation algorithm for the new

constraints. It turns out that applying binarization and only enforcing parity constraints on the new variables is often a bad idea. For our application, an integer programming model for the graphic traveling salesman problem, we observe that parity constraints do not improve the dual bounds, and we provide a theoretical explanation of this effect.

## ■ TA-11

Thursday, 9:00-10:30 - WGS|005

### Collaborative Transportation Planning

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: *Margaretha Gansterer*

#### 1 - Forming near-optimal regions from bids of less-than-truckload logistics providers on country subdivisions in reverse auctions

*Jan-Philipp Eisenbach, Felix Zesch*

Shippers usually contract logistics service providers (LSP) for less-than-truckload (LTL) shipments by giving all transports originating in one region and going to one or more destinations to one single LSP. The assignment of LSPs to regions is usually done in reverse auctions. In the current process, the country needs to be divided into such regions before LSPs can bid on them. In Germany, these regions are often based on arbitrary grouping of administrative divisions such as areas with the same two-digit zip codes. There is no accepted methodology for this decision process. We propose a methodology for dividing a country into regions based on bids from different LSPs on single administrative divisions. Each LSP can reduce costs if the sources of its LTL-shipments are close to each other. Our approach is to have each LSP bid on several single administrative divisions, leaving us to combine them to regions respecting the LSP's general requirements. This creates a geometric set cover problem with additional constraints: a) the regions must not overlap b) they must respect some real-world capacity constraints c) they must respect the bids of each LSP. Our solution proposes to integrate these modifications into the geometric set cover problem and to build an approximation algorithm finding near-optimal cuts through the entire country. After presenting the current and new bidding processes, the new dynamic region cutting methodology with the algorithm developed is compared to the existing static approach with an industry dataset. In addition, we discuss whether an LSP can exploit the new bidding process through untruthful bids. The cost effect of relaxing several constraints is explored, providing managerial insight on the newly designed bidding process.

#### 2 - The benefit of information sharing in horizontal carrier collaborations

*Margaretha Gansterer, Richard Hartl, Martin Savelsbergh*

In horizontal collaborations, carriers form coalitions in order to perform parts of their logistics operations jointly. By exchanging transportation requests among each other, they can operate more efficiently and in a more sustainable way. This exchange of requests can be organized through combinatorial auctions, where collaborators submit requests for exchange to a common pool. These requests are then combined to a set of bundles by a central authority and offered back to all participating carriers. After a bidding phase, the central authority allocates requests to carriers according to their preferences. Gained profits are shared among participating carriers. Such auction-based exchange mechanisms can be performed without any information sharing of carriers' sensitive data. In this study we investigate how shared information in a combinatorial transportation auction improves the total collaboration profit. We develop different concepts, where carriers share aggregated information on their existing customers with (i) the auctioneer and/or (ii) other carriers. Through a computational study we assess the effectiveness of the proposed concepts.

## ■ TA-13

Thursday, 9:00-10:30 - RVH|I

### Feature Engineering, Segmentation and Optimization

Stream: Business Analytics, Artificial Intelligence and

## Forecasting

## Parallel session

Chair: Evren Guney

**1 - A First Derivative Potts Model for Denoising and Segmentation Using MILP***Ruobing Shen, Gerhard Reinelt, Stéphane Canu*

Unsupervised image segmentation and denoising are two fundamental tasks in image processing. Usually, graph based models such as graph cuts or multicut are used for globally optimum segmentations and variational models like total variation are employed for denoising. Our approach addresses both problems at the same time.

An image can be seen as a function  $y: P \rightarrow R$  giving the intensity of pixels located on a finite 2-dimensional grid  $P$ . The segmentation problem is tackled by fitting a piecewise constant function  $f: P \rightarrow R$  to  $y$  minimizing  $\sum_p \text{in } P |f(p) - y(p)|$  with an additional  $L_0$  regularization term to count the number of variations (with respect to segments) per row and column. We propose a novel MILP formulation of a first derivative Potts model, where binary variables are introduced to directly deal with the  $L_0$  norm. The model approximates the values of pixels in a segment by a constant plane and incorporates multicut constraints to enforce the connectedness of segments. As a by-product the image is denoised.

Our approach could also be interpreted as piecewise constant fitting in 2D. To the best of our knowledge, it is the first globally mathematical programming model for simultaneously segmentation and denoising. Numerical experiments on real-world image are carried out against multicut and variational models.

**2 - Long-Term Forecasting: Cross-Impact-Analysis vs. time-sliced Bayesian Networks***Hans-Joachim Lenz, Thomas Schwarz*

The design and production of the automotive industry or the oil exploration and production industry have business cycles of eight, fifteen or up to 60 years. The scenario technique (ST) is a methodology for allowing such long lead times. It enables making assumptions and statements about the future system state with subject, time and region well defined. A 'What-if'-Analysis allows generating various future world states of interest.

ST is a triple  $(G, I, E)$  with  $G = (V, K, P)$  as the model graph,  $V$  a (finite) set of variables (knots) with finite  $\text{Range}(v)$ , where  $v$  is element of  $V$ ,  $K$  is the set of linked pairs of variables,  $v$  and  $w$  are elements of  $V$ ,  $P$  represents a set of measures of uncertainty on  $V$ .  $I$  is a set of restrictions over  $P$ , strongly dependent upon the approach selected, cf. Reibnitz [1991], Pearl (1986), Lauritzen und Spiegelhalter.

Cross-Impact-Analysis (CIA) and dynamic Bayesian Networks (DBN) differ in model and inference, Müller and Lenz [2013]. CIA is a static approach, leads necessarily to too many loops, and considers only bivariate dependencies of attributes. DBN is based on multi-causal influence with interactions but without feedback. While CIA changes uncertainty factors into probabilities in a purely heuristic way, DBN uses decomposition of  $P$  under the Markovian (1st order) assumption, while being restricted to DAGs.

We demonstrate long-term forecasting of the oil price using the DBN scenario technique.

Ref.: Müller und Lenz [2013], Business Intelligence, Springer, Heidelberg

**3 - Efficient Election Campaign Optimization Using Integer Programming***Evren Guney*

Election Campaign Optimization Problem (ECOP) is one of the critical issues in many countries ruled by democracy. During the election campaigns, political parties spend a lot of effort to introduce themselves and invest their resources to convince voters. Given that each political party already has a loyal base community, what becomes important is persuading the so called swing voters - the voters who do not have a clear decision about their choice. ECOP can be described as finding the best way to allocate a political party's resources among different election locations in order to maximize the seats or member of parliaments (MPs) won. The level of effect of advertising on earning votes or winning elections has been studied extensively in the sense of determining the best advertising strategy or determining the marketing mix. However, most of the studies focus on determining the magnitude and significance of the effect of spending through various regression analysis methods. In this study our objective is to determine the election regions

to market heavily so that the party wins extra MPs in those regions. For this purpose, first one has to determine the amount of swing votes for each election region and the minimum amount of votes needed to pass the opponent to win extra seat(s). We carry out our analysis on one of the most popular election rules: D'Hondt rule and derive mathematical formulae to exactly determine the threshold values. Next, we develop mathematical formulations to represent two different versions of the election campaign optimization problem. Last, we perform detailed computational analysis on the Turkish Parliamentary elections to test our methodology, which is generic and can be applied to many many different election methods.

## ■ TA-14

Thursday, 9:00-10:30 - RVH|II

**Customer-Oriented Pricing Mechanisms**

Stream: Pricing and Revenue Management

Parallel session

Chair: Claudius Steinhardt

**1 - Threshold Problems in Ascending Combinatorial Auctions***Bart Vangerven, Dries Goossens, Frits Spieksma*

Combinatorial auctions are auctions that sell multiple items simultaneously and allow bidders to bid on packages of items. Allowing bidders to create custom packages potentially increases economic efficiency and seller revenues. Indeed, when package bids are allowed, the exposure problem is avoided. However, economic efficiency is still hampered by the presence of the so-called threshold problem, which is the phenomenon that multiple "small" bidders (i.e. bidders on sets of items with small cardinality) may not be capable of jointly outbidding a "large" bidder, although the valuation of the bidders would allow the small bidders to do so. This effect is partly attributed to the fact that the small bidders are unaware of each other's presence, and therefore experience no incentive to keep bidding in an ascending combinatorial auction. We study bidding behavior in ascending combinatorial auctions with threshold problems, using different levels of feedback. We do this in an experimental setting using human bidders. We vary feedback from very basic information about provisionally winning bids and their prices, to more advanced concepts as winning and deadness levels, and even so-called coalitional feedback, aimed at helping bidders to overcome potential threshold problems. Hence, the main question we address is the following: "Does additional feedback help bidders overcome threshold problems in ascending combinatorial auctions?" We test this in different auction environments, varying the number of items and bidders as well as the severity of the threshold problem, investigating the effects on economic efficiency, auction revenues, auction duration, etc.

**2 - Pricing with Informative Delay Announcements***Secil Savaseneril, Sirma Karakaya, Yasemin Serin*

We study the pricing problem of a service provider who makes delay announcements to inform the customers about anticipated delays. Besides making price quotes to arriving customers, the provider decides on the amount of delay information to be revealed to the customers. Price and announcement decisions affect the behavior of the customers who are delay- and price-sensitive, which in turn affects the profitability of the firm. We model the system as a stochastic discrete-time Markovian queue, and model the pricing problems through Markov decision process. We compare several delay information and pricing schemes and through analytical results and numerical study identify the conditions that make specific delay information or pricing schemes more preferable. We also analyze the impact of the information asymmetry on the preference of the provider. We consider pricing schemes with varying levels of flexibility, and our findings show that even if the information asymmetry favors the service provider, the delay information scheme might severely curb the benefit of the pricing flexibility. Furthermore, results show that traffic intensity, customer-sensitivity and precision of the price quotes have a significant impact on selecting the delay information scheme.

## ■ TA-15

Thursday, 9:00-10:30 - RVH|III

### Agent Based Modelling and Simulation

Stream: Simulation and Statistical Modelling  
*Parallel session*

Chair: Warren Volk-Makarewicz

#### 1 - Constructing Models of Reduced Complexity from Agent-Based Simulation Data

Mareen Hallier, Carsten Hartmann

Agent-based modelling and simulation has seen a huge increase in interest within operations research in the last decade as a promising approach to model and study the behavior of individuals in complex situations. While agent-based modeling is easily applicable to and has been used in very different application fields, the challenge remains how to analyse and understand the complex simulation output: Agent-based models usually are very complex so that models of reduced complexity are needed, not only to see the wood for the trees but also to allow the application of advanced analytic methods. We show how to construct so-called Markov state models that approximate the original Markov process by a Markov chain on a small finite state space and represent well the longest time scales of the original model. More specifically, a Markov state model is defined as a Markov chain whose state space consists of sets of population states near which the sample paths of the original Markov process reside for a long time and whose transition rates between these macrostates are given by the aggregate statistics of jumps between those sets of population states. An advantage of this approach in the context of complex models with large state spaces is that the macrostates as well as transition probabilities can be estimated on the basis of simulated short-term trajectory data.

#### 2 - An agent-based simulation for analyzing supply chain strategies in the apparel industry

Christian Stummer, Sabrina Backs, Hermann Jahnke, Lars Lüpke, Mareike Stücken

In the past, the aim of minimizing manufacturing costs has dominated the design of supply chains for many companies from the (European) apparel industry, which came along with long-distance shipping from Far East and relatively lengthy production cycles. Today, short throughput times have become another, in some market segments even more important, factor for gaining competitive advantage as flexibility in production allows for adjusting to the rapidly changing fashion trends in these segments. Choosing the 'right' supply chain strategy is well analyzed in literature. However, in an attempt to reduce complexity when modeling the underlying market, recent research limits itself to some selected aspects (e.g., strategic buyers, one period, one product, and one retailer). An agent-based simulation, in contrast, can account for several competing retailers with different supply chain strategies as well as variations of individual consumer preferences over time as a result of word-of-mouth communication and social influence. In our talk, we introduce such a simulation approach. It has been parameterized by means of a conjoint study that provides consumers' preferences for clothes and brands, as well as information on their communication and buying behavior. The possible application of the ABS is illustrated for several supply chain strategies (i.e., fast fashion vs. traditional) with varying communication strategies (e.g., in terms of extent of advertising measures) in several market scenarios (i.e., one market leader vs. few established brands vs. a highly competitive market with many players).

#### 3 - A Methodological Framework for Validating Agent-Based Simulation Models to Support Decision Making

Warren Volk-Makarewicz

We present a flexible framework to model, calibrate, and validate the interactions of heterogeneous decision makers in an agent-based model. In our approach, derived from Partially Observable Stochastic Games, each agent has an individualized information set and model, from which they derive decisions. Agents measure the performance of previous decisions according to one or more metrics. The outcome of their decisions emerges from the combination of all individual models. Agents repeatedly decide and act over multiple turns, continuously updating their information set via observed changes in the environment. For example, in a sponsored search auction, multiple firms bid on the ranking of their advertisements on a website given a particular keyword. In this context, a high ranking of ads is desirable. Thus, agents

can represent firms who place bids based on information on past rankings, the resulting revenues, as well as a given marketing strategy and budget.

Decomposing the agent-based model into agents and their environment allows modelers to calibrate each component separately, estimating their parameters. Outputs from the agents and their interaction with the environment can be validated separately against observations from each component. Systematically validating and calibrating agent-based models ensure that a simulation accurately represents a real-world system. Then, subsequent scenario testing of the model can reproduce separately ascertained properties of that system. In this talk, the modeling emphasis is on the agents.

## ■ TA-16

Thursday, 9:00-10:30 - RBM|1102

### Lot Sizing and Inventory Planning

Stream: Production and Operations Management  
*Parallel session*

Chair: Christoph Johannes

#### 1 - Considering sequence-dependent stochasticity in production schedules

Michael Manitz, Frank Herrmann, Maximilian Munninger

In this paper, we test several model formulations for solving multi-level capacitated lot-sizing & scheduling problems consecutively. To resolve the problem with—in fact stochastically—infeasible production plans due to less detailed capacity calculations, we propose parameter modifications for the big-bucket level. Therefore, we follow three directions to reflect the lower capacity availability or the larger utilized capacity at the scheduling level: for adjusting the model parameters, random variables are introduced (1) for the capacity usage, (2) for the capacity availability, and (3) within a clearing-function approach. First simulation studies for randomly generated sets of jobs show improvements with an exact solution to the underlying optimization problems (with modified parameters).

#### 2 - Production scheduling with discrete perishability of inventories

Mehdi Karimi-Nasab

In this research,  $n$  products should be produced over a number of planning periods under the following conditions: products are to be produced on a single machine over  $T$  planning periods; every period  $t$ , has the total length of GT out of which the machine can be available just for a limited amount of time,  $att$ ; lifespan of product type  $i$  is a stochastic variable,  $l_{si}$ , between  $t_{li}$  and  $t_{ui}$ , and follows from a given general-form probability distribution function  $f(l_{si})$ . Without loss of generality, it is assumed that perishability of the inventories occurs after the available time of that period and before the start of the next period. Also, all of such perished units of products are detected by a periodic inspection system. Hence, no perished items are passed to customers. After formulating the problem as an integer program, a randomized decomposition algorithm is developed to solve the problem.

#### 3 - An extension of the General Lotsizing and Scheduling Problem (GLSP) with volatile energy prices

Christoph Johannes, Matthias Gerhard Wichmann, Thomas Spengler

The demand for electrical power in industrial production processes arises often in high energy costs for companies. Moreover, companies are faced in the course of a more sustainable power generation in the future with volatile energy prices, which have the potential to influence the energy costs significantly. In order to manufacture products at minimal total decision relevant costs energy costs have to be considered in the production scheduling. To date, only few production planning approaches in the field of job-shop scheduling and individual planning approaches in the field of simultaneous Lotsizing and Scheduling deal with volatile energy prices. Up to now, a general model formulation for the consideration of volatile energy prices in Lotsizing and Scheduling and an investigation of appropriate conditions for an energy oriented production planning is missing. In this contribution the Energy Oriented General Lotsizing and Scheduling Problem (EOGLSP) is introduced as an extension of the respected General Lotsizing and Scheduling Problem (GLSP). The cost saving potential by considering energy



costs in the Lotsizing and Scheduling Problem towards classical planning approaches is analysed and appropriate frame conditions are investigated within a structured parameter analysis.

## ■ TA-17

Thursday, 9:00-10:30 - RBM|2204

### Surgery Planning

Stream: Health Care Management  
*Parallel session*

Chair: *Katja Schimmelpfeng*

#### 1 - How starting times influence performance of the operating theater

*Lisa Koppka*

Decision makers in hospitals aim to allocate given capacities best possible to support staff's, patient's and management's interests. This applies in particular to the operating theater, since a large part of revenue and costs emerges here. The allocation of total capacity to different operating rooms determines the respective operating hours - the periods of time in which regular surgeries are to be assigned. Most common in reality is that all operating rooms start simultaneously in the morning. Considering the tendency to flexible shift models for doctors and nurses in order to support work-life balance, starting work later becomes more attractive. In cooperation with one of the biggest heart centers in Germany, we examine the influence of adjusted starting times for operating rooms, while the operating room capacity remains the same. Performance criteria considered are especially over-time, rescheduling of patients and utilization on behalf of staff, patients and management. Results indicate that starting times can strongly influence performance.

#### 2 - Surgery scheduling with consideration of ICU utilization leveling

*Steffen Heider, Sebastian Hof, Jan Schoenfelder, Thomas Kopperna, Jens Brunner*

Cost pressure forces many hospitals around the world to improve their efficiency. As two of the main cost drivers, the operating theater and the ICU have a prioritized role when it comes to analyzing and optimizing the processes in a hospital. The bed occupancy at the ICU is directly connected to the weekday and sequence of surgeries performed in the OR as well as the type of surgery, since the probability of an ICU transfer and the length of stay vary drastically by surgery type. We present a mixed integer quadratic program (MIQP) to minimize the variability of ICU bed demand in a given week by rearranging elective surgeries in the OR. Based on 2 years of available data from our partner the Klinikum Augsburg, we analyze the existing scheduling and compare it with multiple scenarios of our model.

#### 3 - A hybrid simulation-optimization approach for mobile GP operation planning

*Christina Büsing, Martin Comis*

Demographic change lead to a severe shortage of general practitioners in many rural areas of Germany. As a counter-measure, the statutory health insurance pursues the setup of mobile medical units. Mobile medical units allow for an efficient medical coverage of sparsely populated, spacious areas. Unfortunately, flexibility comes at the price of a highly complex operation planning process. In order to solve the resulting operation planning problem, we developed an optimization approach that combines a facility location, routing and scheduling problem. Succeeding this optimization stage, we evaluate our obtained solutions by an agent based simulation tool to predict the resulting coverage of medical treatment based on multiple performance indicators. These predictions are then fed back into our optimization models and the simulation-optimization cycle starts over. We applied this hybrid simulation-optimization approach to a rural area in the German Eifel. In this talk, we present the obtained results.

## ■ TA-18

Thursday, 9:00-10:30 - RBM|2215

### Scheduling in Shops

Stream: Project Management and Scheduling  
*Parallel session*

Chair: *Julia Lange*

#### 1 - Partially Concurrent Open Shop Scheduling with Resource Constraints

*Hagai Ilani, Elad Shufan, Tal Grinshpoun*

Partially Concurrent Open Shop Scheduling (PCOSS) is a relaxation of the well-known Open Shop Scheduling (OSS), where some of the operations that refer to the same job may be processed concurrently. Here we extend the study of the PCOSS model by considering the addition of renewable resources. The purpose of this study is generalization of results from OSS model with resource constraints to the PCOSS model. In particular, we deal with the case of preemption PCOSS, where a few polynomial algorithms are known for its OSS counterpart. We investigate the structure of the conflict graph of a PCOSS instance and focus on the efficiency of solving the problem to optimality. The model has a natural application of assigning technicians to vehicles in a garage where besides the technicians (machines) and vehicles (jobs) there are additional resources, such as vehicle lifts.

#### 2 - A dynamic programming approach for the no-wait job shop problem

*Ansis Ozolins*

We consider the no-wait job shop scheduling problem with no-wait constraints (NWJS). The objective is to minimize a makespan. The majority of research is focused on developing the heuristics. However, only a few exact algorithms are known in the literature. We propose a new exact algorithm, which is based on the dynamic programming (DP). The main elements of the DP algorithm for solving the NWJS are introduced: a graph associated with the problem, the state space, a dominance rule, the Bellman equation, a bounding procedure to reduce the state space of the DP algorithm. As an extension of our algorithm, we also present a heuristic variant of the algorithm. Extensive computational results show that our algorithm is able to solve moderate benchmark instances to optimality in a reasonable time limit. In addition, it is shown that the heuristic DP can obtain good quality upper bounds for large-size benchmark instances.

#### 3 - Neighborhood structures for the blocking job-shop scheduling problem

*Julia Lange, Frank Werner*

By including a real-world aspect in the classical job-shop scheduling problem, the consideration of blocking constraints refers to the absence of buffers in a production or logistics system. In case that the succeeding machine is not idle, a job will block the machine until its processing can be continued. Following customer satisfaction as one of the main goals in many industries, a schedule (i.e., the starting times of the jobs on the machines), which minimizes the total tardiness of all jobs, is to be determined. A job-shop scheduling problem with a total tardiness objective is NP-hard even without blocking constraints and mathematical programming results give evidence to the necessity of heuristic methods to obtain near-optimal solutions even for small instances. One of the main components of most heuristic approaches is the neighborhood structure. Here, the integration of blocking constraints causes significant difficulties, since a permutation of operations does not always define a feasible schedule and it is not clear whether and how a partial solution obtained by a slight change in the schedule can always be completed to a feasible neighbor. For the blocking job-shop problem, a neighborhood, which applies adjacent pairwise interchanges together with a technique to repair and complete partial solutions, is presented. The mechanism is implemented in a simulated annealing metaheuristic and tested on train-scheduling-inspired problems as well as benchmark instances.

## ■ TA-19

Thursday, 9:00-10:30 - RBM|3302

### CANCELLED: Case Studies in Operations Management

Stream: Production and Operations Management  
Parallel session

Chair: *Seydreza Rahnamay Touhidi*

## ■ TA-20

Thursday, 9:00-10:30 - RBM|4403

### Supply Chain Design

Stream: Supply Chain Management  
Parallel session

Chair: *Teresa Melo*

#### 1 - A joint network and inventory modelling approach for lean and agile strategies

*Wan Chuan (Claire) Chan, Johannes Fichtinger*

Supply chain segmentation has become a key competence for companies in increasingly varied market places. It reflects companies' ability to differentiate and manage supply chains at a more granular level but still remain economical. Although there does not appear to be a standardised way, approaches in the literature commonly segment supply chains into lean and agile segments by using product specific criteria. The challenges for companies then are threefold: 1) determining the segmentation criteria, 2) transforming the segmentation strategies into operational activities, and 3) quantifying the impact of applying such a segmented strategy on total cost. Compared with the first issue, much less research effort has been made for the second and third issues. However, current studies still provide a conceptual framework for integrating segmented strategies into supply chain design: tactically, by determining the level of centralisation, and operationally, via any methods to shorten lead times and to optimise inventory levels. In this paper, we address the second and third issues by proposing an approach to jointly optimise the network configuration and segmentation based on segmentation criteria (e.g. volume and variability of demand). We include safety stock placement as one of the key decisions to assess the impact of uncertainty in differentiating supply chain design. Particularly, we adopt the guaranteed service model to optimise safety stock while considering risk pooling effects. In addition, we consider other tactical aspects such as the consolidation effect in transportation. We show how a supply chain can be segmented into different network structures when risk pooling and consolidation effects are considered and evaluate the benefits through numerical analyses.

#### 2 - A Distribution Planning Method for the Regional Logistics Center Considering Carbon Emissions

*Jun-Der Leu, Jin-Jen Liu, Yi-Wei Huang, Larry Jung-Hsing Lee, Andre Krischke*

One major function of a regional logistics center is to provide an effective distribution service using the limited transportation capacity to fulfill the demands of local marketing channels. In it, the cargo distribution needs transportation vehicles, while the vehicles lead to carbon emission. Considering many green regulations, these carbon emissions are counted in the carbon footprint of the related products.

According to the MOBILE5 Vehicle Emissions Model, traveling distance and speed is significant influence factors to the carbon emissions of transportation. Normally the logistics planning are defined by mathematical planning or discrete mathematics models, on which algorithms or heuristics are developed to optimize the distribution logistics. However, most of these models are static ones, which follow the assumptions of stable traffic and fixed traveling speed on the network so that a significant error might happened when they applied to the green logistics directly. Further, in reality, the traffic situations are not stable all the time, when facing traffic jams, vehicles move in low speed, and the carbon emissions increase. Again, these models do not consider the issue of oil consumption and carbon emission caused by the dynamic traveling speed.

In this research, the cargo flows modeling approach is applied to analyze the logistics planning scenario of single logistics center to many

demand depots in the market region, wherein both of distribution logistics as well as carbon emission will be well considered. The planning algorithms were developed, and the computer simulation method was applied to validate the solution quality in terms of different transportation network scale and traffic heavy level.

#### 3 - A Mixed-Integer Programming Model for Green Location and Transportation in a Closed-Loop Supply Chain

*Turan Paksoy, Ahmet Çalık, Abdullah Yıldızbaşı, Alexander Kumpf*

Nowadays, due to the increasing of the importance of climate change and global warming, numerous legislations and regulations reducing the environmental impact of supply chains have been published in the world. Therefore, Green Supply Chain Management (GSCM) has emerged as an important paradigm for the companies. In this paper, we investigate the environmental considerations through a new Closed-Loop Supply Chain (CLSC) model. We deal with green or sustainable location and transportation issues to decide on the optimal locations of plants, collection centers and refurbishing centers for new products and used products in order to minimize the total supply chain cost and carbon-dioxide emission regarding the technology level (low, medium, high) of potential plants. Herein, low technology level refers to lower fixed facility costs but higher carbon-dioxide emission levels at plants. Contrarily, high technology refers to higher fixed facility costs but lower environmental costs at plants. By the means of green transportation, the proposed model makes a trade-off between transportation cost and carbon-dioxide emission cost. We consider that all the transportation in the network is outsourced from a logistics firm where three different types of vehicles are used for transportation. Load ranges that can be transported with each of these vehicle types are pre-determined. Transportation costs can be reduced by choosing large-sized trucks but it causes to negative environmental effects when it compares to small-sized trucks. To handle these kinds of conflicts, we propose a mixed-integer linear programming (MILP) model. A numerical example is implemented and analyzed in order to demonstrate the efficiency of the developed model.

#### 4 - A tri-objective multi-period model to redesign a food bank supply chain network

*Teresa Melo, Carlos Lúcio Martins, Margarida Vaz Pato*

Motivated by the increasing global interest in reducing food waste, we address the problem of redesigning a multi-echelon supply chain network for the collection of donated food products and their distribution to non-profit organizations that provide food assistance to the needy population. For the social organization managing the network, important strategic decisions comprise opening new food bank warehouses and selecting their storage and transport capacities from a set of discrete sizes over a multi-period planning horizon. Facility decisions also affect existing food banks that may be closed or have their capacity expanded. Logistics decisions involve the number of organizations to be supplied, their allocation to operating food banks, and the flow of multiple food products throughout the network. Decisions must be made taking into account that food donations are insufficient and a limited investment budget is available. We propose a novel mixed-integer linear programming (MILP) model that accounts for sustainability by integrating economic, environmental, and social objectives. To this end, three objective functions are defined: (i) minimization of the cost of operating the food bank network, (ii) minimization of the environmental impacts of food waste and CO<sub>2</sub> emissions, and (iii) maximization of the social benefits generated for organizations supported by food banks. A computational study is conducted to investigate the trade-offs achieved by considering the three conflicting objective functions. Using a general-purpose solver, lexicographic optimal solutions are identified for instances capturing various characteristics of the network coordinated by the Portuguese Federation of Food Banks.

## ■ TA-21

Thursday, 9:00-10:30 - RBM|4404

### Miscellaneous

Stream: OR in Engineering  
Parallel session

Chair: *Zuzana Nedelkova*

### 1 - Scheduling a manufacturing process with several rail-bound and identical machines in the project EWiMa

Markus Schreiber

In the project EWiMa, efficient procedures for the manufacturing of wing covers are developed. One major objective is the manufacturing of such a component on GroFi'. GroFi is a technology demonstrator for an innovative manufacturing plant that is specialized on the production of large-scale lightweight components. It is developed by the DLR in Stade (Germany). A special feature of the plant is the possibility to split steps of the production process between several identical production-units. The units are mobile on a rail network. It is expected that the production process is drastically shortened by synchronizing those steps. Among other problems the scheduling of the cooperating units is investigated by the DLR. In the project EWiMa, the usage of two synchronized fibre-placement units for the manufacturing process will be demonstrated for the first time. The schedules are calculated with a model that has been derived from the Quay Crane Scheduling Problem. The proposed presentation will describe the problems and conditions that have been considered for the scheduling. Furthermore the discrepancy between the modelled and the real execution times is examined to identify future improvements.

### 2 - Development of Optimal Transit Routes in Afghanistan

Fawad Zazai

Afghanistan is a landlocked country at the intersection between South and Central Asia. Three-quarters of the country consists of inaccessible mountainous regions. It is the intention of the Afghan government to turn the country into a so-called "logistical crossroad" - transit country by air, land and sea routes (rivers and sea routes in the ocean as part of a longer route) in Central Asia between the neighboring countries China, Iran, Tajikistan, Uzbekistan, Turkmenistan and Pakistan.

The aim of this study is to develop optimal transit routes in Afghanistan by mathematical optimization methods. The focus will be set on the optimal development of infrastructure in Afghanistan, which extends later to the South and Central Asian region. In the present initial research phase we focus on the shortest path problem between two cities. The path from one city to an other city may across mountains and canyons. The shortest path problem deals with the issue, how to find an optimal route between two nodes or points (start and end point)? An optimal route may be optimal a) with respect to the length of the route, b) regarding the construction cost of the route, or c) with respect to the height variation of the route. To solve the shortest path problem we use the Dijkstra's algorithm.

### 3 - A splitting algorithm for simulation-based optimization problems with categorical variables

Zuzana Nedelkova

In the design of complex products some product components can only be chosen from a finite set of options. Each option then corresponds to a multidimensional point representing the specification of the chosen components. We present a splitting algorithm that explores the resulting discrete search space and is suitable for optimization problems with simulation-based objective functions. The splitting rule is based on the representation of a convex relaxation of the search space in terms of a minimum spanning tree and adopts ideas from multilevel coordinate search. The objective function is underestimated on its domain by a convex quadratic function. Our main motivation is the aim to find—for a vehicle and environment specification—a configuration of the tyres such that the energy losses caused by them are minimized. Numerical tests on a set of optimization problems are presented to compare the performance of the algorithm developed with that of other existing algorithms.

## ■ TA-22

Thursday, 9:00-10:30 - HFB|A

### MCDM 3: Real-World Applications

Stream: Decision Theory and Multiple Criteria Decision Making

Parallel session

Chair: H.a. Eiselt

### 1 - Sustainable tourism destination selection under the effect of digital economy

Erdem Aksakal

In today's world, tourism become an enormous and widespread industry. The tourism can be defined as the activities of people for travelling or staying outside of the usual place for recreation, leisure, family or business purposes for a limited time. It is found all over the world and impacts social, economic, and environmental part of our lives. As being a part of our lives, it needs to be sustainable. According to the World Tourism Organization (WTO) sustainable tourism defined as "Tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities". Sustainable tourism usually aims to have minimal negative impacts such as to minimize harm, and to have maximum positive impacts such as optimize economic benefits. Nowadays with the growing population and mobilization, digital economy begins to affect every aspect of our lives. For tourism business, the Internet (as being a part of digital technology) plays an important role as offering potential to make information and booking facilities to large numbers of tourists. The aim of this study is to provide a fuzzy decision making model for sustainable tourism destination selection under the effect of digital economy. To select the appropriate destination, the criteria were selected from the "Making Tourism More Sustainable: A Guide for Policy Makers" according to the effect of digital economy. The decision process consists of six criteria as Economic Viability, Local Prosperity, Employment Quality, Social Equity, Local Control, Cultural Richness. The regions and the countries identified from World Tourism Organization's data. Fuzzy TOPSIS method used to find the appropriate destination selection.

### 2 - Multiobjective Spatial Optimization: The Canadian Coast Guard

H.a. Eiselt, Amin Akbari, Ronald Pelot

This presentation examines a problem of the Canadian Coast Guard. The mission of the Coast Guard (Atlantic) is to provide assistance to vessels or persons aboard that are in distress. This piece focuses on the search & rescue mission of the Coast Guard. The two most important criteria include the average time that it takes to reach a vessel in distress, and the number of vessel incidents that can be reached within a reasonable time limit. Given that demand throughout the year is not constant but peaks during the summer season (in excess of 50% of the distress calls occur in July and August), there is a potential for congestion and the resulting inability of the Coast Guard to answer distress calls within an acceptable amount of time. In order to avoid formulating the model as a probabilistic model with all its computational difficulties, we use backup coverage as a third important concern. We model the problem of locating different types of rescue vessels along the coastline of the Maritime Provinces as an integer programming problem with three objectives, each dealing with one of the major concerns. The problem is solved given the available vessels and on the basis of incidents reported in the past. The solution is compared to the arrangement that is presently used by the Coast Guard.

## ■ TA-23

Thursday, 9:00-10:30 - HFB|B

### Optimization and Market Design (i)

Stream: Game Theory and Experimental Economics

Parallel session

Chair: Martin Bichler

### 1 - Linear pricing in double auction markets with non-convexities

Vladimir Fux

Linear and anonymous competitive equilibrium prices are desirable in multi-item auctions, but unfortunately they do not always exist in non-convex markets. Still, day-ahead energy markets allow for package bids and determine linear and anonymous prices, even though they do not constitute competitive equilibrium prices. Linearity and anonymity are not only a concern on energy markets, but they are not well understood. We discuss the market design for a large-scale combinatorial exchange for fishery access rights. The specifics of the allocation problem lead to different ways on how allocation and payments are computed. We analyze trade-offs of different payment rules relevant to an auction designer. Similar market design problems can be found in other parts of the world and other application domains.

## 2 - Core allocations in combinatorial exchanges with budget constraints

*Stefan Waldherr, Martin Bichler*

We consider combinatorial exchanges in which buyers face exogenous budget constraints that may restrain them from bidding up to their full valuation for their desired bundles. Budget constraints are very important in the field and have been a significant topic in the mechanism design literature. It can be shown that incentive-compatible mechanisms are impossible to achieve with private budget constraints. Unfortunately, even if bidders are not strategic, we cannot always hope for welfare maximization and a competitive equilibrium in a market where buyers have budget constraints. In contrast to classical equilibrium theory, the welfare maximizing allocation might not give rise to a competitive equilibrium and calculating a stable outcome can lead to significant computational complexity as the allocation problem is not independent from the pricing problem anymore. Moreover, one can show that the core can be empty. In this talk, we discuss the challenges of combinatorial exchanges under budget constraints, discuss the complexity of finding core allocations and propose a bilevel programming approach to determine core allocations with high social welfare in the case that the core is not empty.

## 3 - Linear Item Pricing In Combinatorial Auctions

*Robert Day*

I will present new results regarding the use of linear item prices in combinatorial auctions. Prices for items form a solution to an altered dual of the winner-determination problem, are core-selecting, and constitute a combinatorial competitive equilibrium.

## ■ TA-24

*Thursday, 9:00-10:30 - HFB|C*

### Nonlinear Optimization 1

Stream: Control Theory and Continuous Optimization  
*Parallel session*

Chair: *Faizan Ahmed*

#### 1 - Robust optimization methods for circle coverings of a square

*Mihály Csaba Markót*

In the talk we are dealing with coverings of a square with uniform circles of minimal radius, with uncertainties in the actual placement of the circles. We assume that each circle centre is located in given regions of uniform shape and size. (Hence, we skip the question of how the regions are generated; they may come, e.g., as confidence regions of a probability model of the problem.) This is an example model of, e.g., deploying sensors so that there are uncertainties in the realization of the process. Possible sources of the uncertainty include scenarios when the deployment have to be made remotely (e.g., from the air) into a potentially dangerous place, deployments into a location with unknown terrain, or deployments influenced by the weather.

Our goal is to produce coverings that are optimal in terms of a minimal radius, and are also robust in the following sense: wherever the circles are actually placed within the given uncertainty regions, the result is still guaranteed to be a covering. We investigate three special uncertainty regions: first we prove that for uniform circular uncertainty regions the optimal robust covering can be created from the exact optimal circle covering without uncertainties, provided that the exact covering configuration is feasible for the robust scenario. We also investigate uncertainty regions given by line segments and general convex polygons. For these latter settings we design a bi-level optimization method that combines a complete and rigorous global search using interval arithmetic, and a derivative free black-box search. We show the efficiency of our proposed method on some examples.

#### 2 - Computing the splitting preconditioner for interior point method using an incomplete factorization approach

*Marta Velazco, Aurelio Oliveira*

The search directions in the interior-point method for linear programming are computed through the solution of one or more linear systems. The solution of such linear systems is the most expensive step of these

methods. The performance of the implementations using an iterative solution depends upon the choice of an appropriate preconditioner. In particular, for interior point methods, the linear system becomes highly ill-conditioned as an optimal solution is approached. The splitting preconditioner is very effective when applied together with the conjugate gradient method, in the final iterations, for the linear systems arising from interior point methods. These preconditioners rely on an LU factorization of an a priori unknown linearly independent subset of the linear problem constraint matrix columns. However, that preconditioner is expensive to compute since a non-singular matrix must be built from such set of linearly independent columns. In this work, a new version of the splitting preconditioner is presented dropping the need to obtain a non-singular matrix. The controlled Cholesky factorization is used to compute the preconditioner from the normal equations matrix from a given set of not necessarily independent columns. Such an approach is practicable since the controlled Cholesky factorization may be computed by adding suitable diagonal perturbations with a polynomial shift strategy. Numerical experiments show that the new approach improves previous performance results for both robustness and time on some large-scale linear programming problems.

## ■ TA-25

*Thursday, 9:00-10:30 - HFB|D*

### Energy and Stochastic Programming

Stream: Energy and Environment  
*Parallel session*

Chair: *Dogan Keles*

#### 1 - Strategic generation investment using a stochastic rolling-horizon MPEC approach and adaptive risk management

*Thomas Kallabis, Steven Gabriel*

Investments in power generation assets are multi-year projects with high costs and multi-decade lifetimes. Since market circumstances can significantly change over time, investments into such assets are risky and require structured decision-support systems. Investment decisions and dispatch in electricity spot markets are connected, thus requiring anticipation of expected market outcomes. This strategic situation can be described as a bilevel optimization model. At the upper level, an investor decides on investments while anticipating the market results. At the lower level, a market operator maximizes revenue given consumer demand and installed generation assets as well as producer price bids.

In this paper, we reformulate this problem into a mathematical program with equilibrium constraints (MPEC). We extend this model to include a dynamic rolling-horizon optimization. This structure splits the investment process into multiple stages, allowing the modification of wait-and-see decisions. This is a realistic representation of actors making their decision under imperfect information. Furthermore, we model an endogenous learning algorithm that allows updating risk-aversion parameters. These two extensions allow us to investigate the success of learning algorithms in strategic investment decisions. Lastly, the rolling-horizon formulation also has computational advantages over a perfect foresight and we provide supporting numerical results to this point.

#### 2 - A stochastic energy system model to investigate efficient markets for security of supply in Europe - and challenges when applying the model to high performance computing

*Frieder Borggrefe, Manuel Wetzel*

This paper develops a stochastic multi stage decomposition approach to model balancing markets and markets for security of supply in electricity systems. It provides insights from a simplified model and proposes an application to high performance computing in order to scale the model to represent the full European electricity system.

The European winter package presented in December 2016 provided a series of regulations and directives for a new energy market design. The market design however falls short to provide a market based approach to security of supply. In this paper we provide the concept for a stochastic energy system model incorporating day-ahead, intraday and real-time markets on the one hand and the emergency measures currently triggered by the TSOs on the other hand. We propose different market designs and outline how they can be modelled.

Based on a simplified energy system model we outline the concept of the model and compare the proposed market designs. In order to scale such a model to the European electricity system and model different levels of system adequacy sufficiently an application to high performance computing (HPC) is proposed. The last part of the paper discusses how the model can be applied to HPC. Based on the simplified electricity model different implementations and algorithms are tested to efficiently use distributed calculations. We outline the next steps necessary to scale and implement the model to HPC.

### 3 - Biomass Supply Planning for Combined Heat and Power Plants using Stochastic Programming

*Daniela Guericke, Ignacio Blanco, Juan Miguel Morales, Henrik Madsen*

During the last years, the consumption of biomass to produce power and heat has increased due to the new carbon neutral policies. Nowadays, many district heating systems operate their combined heat and power (CHP) plants using different types of biomass instead of fossil fuel, especially to produce heat. Since the biomass transport from the supplier to the consumption sites can be long and the contracts are negotiated months in advance, the negotiation process involves many uncertainties from the energy producer's side. The demand for biomass is uncertain at the time of negotiation, and heat demand and electricity prices vary drastically during the planning period. Furthermore, the optimal operation of combined heat and power plants has to consider the existing synergies between the power and heating systems while always fulfilling the heat demand of the system.

We propose a solution method using stochastic programming to support the biomass supply planning for combined heat and power plants. Our two-phase approach combines mid-term decisions about biomass supply contracts with the short-term decisions regarding the optimal market participation of the producer to ensure profitability and feasibility. The risk of major deficits in biomass supply is reduced by including appropriate risk measures to the models. We present numerical results and an economic analysis based on a realistic test case.

### 2 - Social Learning and the Endowment Effect: An Experiment

*Timo Heinrich, Matthias Seifert, Franziska Then*

In this study we analyze the influence of social learning on the endowment effect. We present the results from an experiment disentangling the effects of learning on a market for insurance. In our baseline treatment we privately elicit valuations from market participants trading an insurance protecting them from a potential lottery loss. In our main treatment we elicit the same measures but inform market participants about others' valuations allowing for social learning.

## ■ TA-26

*Thursday, 9:00-10:30 - HFB|Senat*

### Decision Making under Uncertainty (i)

Stream: Game Theory and Experimental Economics

*Parallel session*

Chair: *Timo Heinrich*

#### 1 - An experimental approach to investigate whether and how risk attitudes change

*Jonas Dörlöchter, Erwin Amann*

After the financial crisis, studies about changes in risk taking comes back to the fore. In addition to the influence of exogenous shocks, experiences from past decisions can also affect risk taking. We are currently working on a lab experiment, which concentrates on whether and how prior outcomes affect risk attitude. Participants will be confronted with identical lotteries in twenty successive periods and have to decide to split their current wealth between a risky and a save investment. After each decision, the lottery will be played out directly and the result determines the wealth of the next period. Whereas most previous studies have documented changes in risk attitudes, using only decisions in at most two successive periods (e.g. Weber and Zuchel (2005)), our study identifies changes, in a series of 20 successive periods. Our results are potentially relevant to modeling risk preferences in multiperiod investment decisions. We base our analysis on an expected utility approach, taking the HARA utility function (Dorloechter and Amann (2017)). This goes in line with findings on absolute risk tolerance as an increasing function of consumers resources (Guiso and Paiella (2008)). In contrast to previous studies, we can thus distinguish between different determinants of changes in investor risk taking, e.g. the discrimination between risk preferences and (subjective) expectations. We try to examine the risk competence of the participants by asking for their risk attitude in a questionnaire and comparing this self assessment to their actual decision. To find out whether and which factors influence the link between outcome and risky choice (escalation of commitment vs. house-money effect), we introduce two treatments: Fixed initial wealth vs. per period income.

## Thursday, 11:00-12:30

### ■ TB-01

Thursday, 11:00-12:30 - WGS|101

#### Nonlinear problems under uncertainty

Stream: Optimization under Uncertainty

Parallel session

Chair: Raimund Kovacevic

##### 1 - Optimal control and the Value of Information for a Stochastic Epidemiological SIS-Model

Raimund Kovacevic

This paper presents a stochastic SIS-model of epidemic disease, where the recovery rate can be influenced by a decision maker. The problem of minimization of the expected aggregated economic losses due to infection and due to medication is considered. The resulting stochastic optimal control problem is investigated on two alternative assumptions about the information pattern. If a complete and exact measurement is always available, then the optimal control is sought in a state-feedback form for which the Hamilton-Jacobi-Bellman (H-J-B) equation is employed. If no state measurement is available at all, then the optimal control is sought in an open-loop form. Given at least an estimated initial probability density for the number of infected, the open loop problem can be reformulated as an optimal control problem for the associated Kolmogorov forward equation (describing the evolution of the probability density of the state). Optimality conditions are derived in both cases, which requires involvement of non-standard arguments due to the degeneracy of the involved H-J-B and Kolmogorov parabolic equations. The effect of the observations on the optimal performance is investigated theoretically and numerically.

##### 2 - Convex Approach with Subgradient Method to Robust Service System Design

Jaroslav Janacek, Marek Kvet

A robust design of a service system operating on a real transportation network has to be resistant to randomly appearing failures in the network. To achieve the resistance, a finite set of failure scenarios is generated to cover the most fatal combinations of the failures. Then, the system is designed to minimize the maximal detrimental impact of the individual scenarios. In the case of an emergency system design, a given number of facilities is to be deployed over a set of possible locations so that the sum of weighted time distances from users' locations to the nearest service center is minimal. The considered randomly occurring failures affect the time distances from the users' locations to the nearest facility locations. As the emergency system design can be modelled as a weighted p-median problem, the failures influence only the coefficients of the objective function. This way, each scenario corresponds to a particular objective function, and thus searching for the robust emergency system design consists of minimizing the maximum of the particular objective functions. While a simple weighted p-median problem is easily solvable, the robust system design is hard to be solved from the two reasons. The first one consists in the size of the resulting model of the problem. The second one originates in usage of min-max constraints, which link up the individual scenario objective functions with their upper bound representing the objective function of the robust problem. The min-max link-up constraints represent an undesirable burden in any integer programming problem due to bad convergence of the branch-and-bound method. In this paper, we focus on handling big size of the original model by employing newly suggested approach based on convex combination of the scenarios.

##### 3 - Scenario Dominance for Acceleration of Robust Service System Design Method

Marek Kvet, Jaroslav Janacek

The goal of a robust system designer is to construct a system, which is resistant to randomly occurring failures as much as possible. In this paper, we focus on the robust design of emergency service system, where a given number of facilities must be located at some elements of the set of possible facility locations so that the sum of weighted time distances from users' locations to the nearest place of a located facility is minimal. The weights of the distances are usually proportional to population in the individual users' locations. When such problem is solved under standard conditions in the underlying transportation network, it can be formulated as the weighted p-median problem with a

broad spectrum of solving techniques. The demand for robustness of designed emergency system brought constitution of detrimental scenarios on the scene. The scenarios comprise impact of fatal combinations of possible failures on time distances between possible facility locations and users' locations. Each scenario corresponds to a particular objective function, and thus searching for the robust emergency system design is solved as minimizing the maximum of the particular objective functions. The resulting problem is hard to be solved due to the size of the resulting model and usage of min-max constraints, which link up the individual scenario objective functions with their upper bound representing the objective function of the robust problem. The min-max link-up constraints represent an undesirable burden in any integer programming problem due to bad convergence of the branch-and-bound method. We focus here on handling big size of the original model by scenario dominance analysis to reduce the set of scenarios and to accelerate associated solving methods.

### ■ TB-02

Thursday, 11:00-12:30 - WGS|102

#### Implementation of Acceleration Strategies from Mathematics and Computational Sciences for Optimizing Energy System Models

Stream: Software Applications and Modelling Systems

Parallel session

Chair: Felix Cebulla

##### 1 - Getting linear optimising energy system models ready for High Performance Computing

Manuel Wetzel, Karl-Kien Cao, Frederik Fiand, Hans Christian Gils

State-of-the-art energy system models include a comprehensive representation of energy sectors and their associated technologies in high spatial and temporal resolution. This complexity is increased further by technologies linking the system along temporal, spatial and sectoral dimensions such as electrical energy storage units, transmission grids or combined heat and power plants. One of the downsides of the increasing detail in linear optimising energy system models is the necessary time to solve the model. The BEAM-ME project addresses the need for efficient solution strategies for complex energy system models. The project brings together researchers from the fields of energy systems analysis, mathematics, operations research, and informatics and aims at developing technical and conceptual strategies for every step of the solution process. This includes changes to the formulation of the energy system model, improving the solvers and utilising the resources of high performance computing. This talk provides an overview of the challenges in adapting the formulation of the energy system model REMix to utilise a solver based on a parallel interior point method. The solver exploits the underlying block structure of the model while maintaining the ability to find the global optimal solution. The block structure has to be communicated to the solver by annotating the energy system model. First insights of current results are discussed and an outlook on future steps is given.

##### 2 - Optimizing large-scale linear energy problems with block diagonal structure by using parallel interior-point methods

Daniel Rehfeldt, Ambros Gleixner, Thorsten Koch

In the wake of the Fukushima nuclear accident in 2011, the German government initiated a policy (named "Energiewende") to shift energy systems towards sustainable, renewable technologies. Since this transition comes with a massive decentralization and a concomitant increase in the size of realistic energy models, 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) that exhibit a block-diagonal structure with both linking constraints and linking variables. In this talk, initial results of adapting the parallel interior point solver PIPS-IPM for these energy LPs are presented. In particular, the underlying mathematically approach will be presented and the practical implications of employing supercomputers to implement this approach are discussed, both with respect to solution time and to solvability.

### 3 - High Performance Computing with GAMS

*Frederik Fiand, Michael Bussieck*

BEAM-ME is a project funded by the German Federal Ministry for Economic Affairs and Energy and addresses the need for new and improved solution approaches for energy system models of vast size. The project unites various partners with complementary expertise from the fields of algorithms, computing and application development.

The main focus is on large-scale linear programs (LPs) arising from energy system models. Such models have a block structure that is not well exploited by state-of-the-art LP solvers. Without considering this structure the models become quickly computationally intractable. Within the BEAM-ME project, new solution algorithms that exploit the block structure and utilize the power of High Performance Computers (HPC) are developed and will be made available to energy system modelers. Automatic detection of block structures in models has its limits and hence the user needs to provide block structure information via some model annotation. GAMS for some time has facilities to annotate a model. We discuss some extensions to the GAMS language which forms the interface between the energy system modeler and the newly developed algorithms.

We provide an overview on the large variety of challenges we are facing within this project, present current solution approaches and provide first results.

### 4 - High Performance Computing for Energy System Modelling

*Thomas Breuer, Dmitry Khabi*

The common approach to solve linear program (LP) arising from an energy system model (ESM) is based on the shared memory paradigm. However, the apparent simplicity of the non-uniform memory access architecture (NUMA) limits the scalability of the underlying hardware components, such as the memory and compute units. On the other hand, increasing of the resolution in spatial and temporal data of ESM requires more and more computational resources. High Performance Computing (HPC) provides a technical solution to overcome these limitations. Use of HPC demands changes to the existing ESM solving framework. This talk presents the latest results obtained in the BEAM-ME project. We discuss the central questions that came up during integration of the parallel optimization solver PIPS in the framework of GAMS language, which is widely used in the field of ESM. Based on a block structured (stochastic) linear problem, the results regarding the scalability and efficiency of the HPC solution were obtained on two Petaflops supercomputers: Hazel Hen, a Cray XC40-system, at High Performance Computing Center Stuttgart (HLRS) and JURECA, a fat tree EDR-InfiniBand cluster, at Jülich Supercomputing Centre (JSC).

Pareto front (a posteriori approach). The possibility of computing all Pareto optimal supplier portfolios is beneficial for decision makers as they can compare all optimal solutions at once, identify the trade-offs between the criteria, and study how the different aspects of supplier portfolio configuration may be balanced to finally choose the composition that satisfies the purchasing company's strategy at best. The approach has been applied to a real-world supplier portfolio configuration case to demonstrate its applicability and to analyze how the consideration of sustainability requirements may affect the traditional supplier selection and purchasing goals.

### 2 - How to control a reverse logistics system when used items return with diminishing quality

*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 are considered to be as good as new and can serve the product demand on a par with the new ones. New and as-good-as-new items are kept in stock, from which the product demand is 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 Schradly (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). We extend this line 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 control policy for such a system.

### 3 - Integrating item-sharing and crowdshipping as a 3-dimensional assignment problem

*Moritz Behrend, Frank Meisel*

An emerging concept of the sharing economy is the so-called item-sharing in which members of a sharing community can temporarily rent items from one another (peer-to-peer). This concept is particularly useful for items that are needed on rare or just temporal occasions like, for example, tools or leisure equipment. The matching of supplies and requests for such items is typically coordinated via on-line platforms. The actual forwarding poses a transportation challenge, as the peer-to-peer exchange needs to address the highly inefficient 'last mile' twice. Crowdshipping is another concept of the sharing economy that provides an innovative means of transport. Registered private drivers with upcoming planned trips by car, detour from their direct route within certain bounds to pickup an item at its current location and to deliver it to the location where it is requested. Item-sharing and crowdshipping has been dealt with separately so far. However, an integration seems reasonable as it enables potentially more efficient and service-oriented alternatives to having users pick up the assigned items by themselves. In this talk, we model the resulting logistics-planning problem on a network of given supplies, requests, and planned trips of the community members. Mathematical optimization models and heuristics are developed to coordinate the assignment of supplies to requests and the assignment of the resulting delivery jobs to crowdshippers. We evaluate the potential of such an integration based on results from computational experiments. We further point out influential factors, identify critical values, and discuss relations that arise from such an integration.

## ■ TB-03

Thursday, 11:00-12:30 - WGS|103

### Sustainable Logistics

Stream: Logistics and Freight Transportation  
Parallel session

Chair: *Moritz Behrend*

#### 1 - Multi-objective supplier portfolio configuration under supply risk and sustainability considerations: an a posteriori decision support methodology

*Florian Kellner, Bernhard Lienland, Sebastian Utz*

This research presents a novel, state-of-the-art methodology for solving the multi-criteria supplier selection problem under risk and sustainability considerations. Our approach combines multi-objective optimization with the analytic network process to meet the requirements for supplier portfolio configuration with sustainability considerations. To integrate the aspect 'risk' into the supplier selection problem, we developed a multi-objective optimization model based on the investment portfolio theory introduced by Markowitz. Our model is a non-standard portfolio selection problem with four objectives: to minimize the purchasing costs, to select the supplier portfolio with the best logistics service, to minimize the supply risk, and to order as much as possible from those suppliers with outstanding sustainability performance. We solve the optimization model, which has three linear and one quadratic objective function, with an algorithm which analytically computes a set of efficient solutions and provides graphical decision support by a visualization of the complete and exactly-computed

## ■ TB-04

Thursday, 11:00-12:30 - WGS|104

### Algorithms for NP-hard Problems

Stream: Graphs and Networks  
Parallel session

Chair: *Ernst Althaus*

### 1 - Arboreal bipartite matchings

*Stefan Canzar, Luka Borozan, Khaled Elbassioni, Sören Laue, Domagoj Matijević*

In this work we study a constrained variant of the bipartite matching problem. The constraints are imposed by two trees that connect the vertices in the two parts of the graph: Two matched vertices in one tree must be in the same ancestry relationship as the two vertices they are matched to in the second tree. We show that the problem of finding such an arboreal matching of minimum cost is NP-hard. We propose an ILP formulation that allows to compute a metric distance based on arboreal matchings between phylogenetic trees in reasonable time. We further develop cutting planes that can be separated in polynomial time to solve larger instances occurring in computational biology.

### 2 - Resolving Conflicts for Lower-Bounded Clustering

*Henning Fernau, Katrin Casel*

For most clustering problems, the quality of a solution is usually assessed with respect to a given pairwise distance on the input objects. Approximate solutions for such tasks often rely on this distance to be a metric. But what happens if this property does not hold? Especially for computing a clustering such that each cluster has a certain minimum cardinality  $k > 2$  (as required for anonymisation or balanced facility location problems) this becomes problematic. For example, with the objective to minimise the maximum radius of all clusters, there exists no polynomial-time constant factor approximation if the triangle inequality is violated while there exists a 2-approximation for metric distances. We try to resolve or at least soften this effect of non-metric distances by devising particular strategies to deal with violations of the triangle inequality (conflicts). With the use of parameterised algorithmics, we find that if the number of such conflicts is not too large, constant factor approximations can still be computed efficiently.

### 3 - Solving SAT-Instances with Small Treewidth within the Apache Spark Framework

*Ernst Althaus, Vitali Diel, Andreas Hildebrandt*

We implemented a SAT-solver based on a tree decomposition within the Apache Spark framework. Due to some preprocessing that reduces the width of the tree decomposition, we were able to solve some instances not solved by any of the solvers participating in the last SAT-competition. This indicates that our approach can be superior in some situations.

### 2 - Train service rescheduling considering energy consumption and passenger compensation policy in case of delays

*Luis Cadarso*

In a railway network, incidents may cause traffic to deviate from the planned operations making impossible to operate the schedule as it was planned. In such a case, the operator needs to adjust the schedule in order to get back to the original schedules. Because a train operator may have the policy of economically compensating passengers when they incur in delays, it is important to have a way of deciding whether to speed up trains in order to absorb delays or to compensate passengers. In this paper a mathematical model which decides on the speed profile while considering passenger use is presented. The model decides on the optimal sequence of operating regimes and the switching points between them for a range of different circumstances and train types all while considering delays, passenger compensation policies, track specific constraints and train conflicts. The objective of this paper is to minimize both energy consumed and incurred compensation to passengers. Computational tests on realistic problem instances of the Spanish rail operator RENFE are reported.

### 3 - The Stable Set Problem with Multiple-Choice Constraints on Staircase Graphs

*Oskar Schneider, Andreas Bärmann, Thorsten Gellermann, Alexander Martin, Maximilian Merkert*

In this talk, we present a generalization of project scheduling with precedence constraints for which it is still possible to give a totally unimodular description. We present five different formulations for the problem as an integer program, which we group into three classes. The first class contains intuitive formulations, where the constraints directly represent compatible choices. The second class contains improved formulations which describe the convex hull of all integer feasible points. The last class contains a dual flow formulation, whose advantage is its sparsity. We test our formulations on a peak load minimization problem with our project partner Deutsche Bahn AG. In the problem, a given timetable draft shall be adapted via small changes in the departure times of the trains to smoothen the power consumption profile. Project scheduling with precedence constraints appears as substructure here. The computational results show that the dual flow formulation outperforms all other formulations and in general is two orders of magnitude faster than the intuitive descriptions.

## ■ TB-05

Thursday, 11:00-12:30 - WGS|104a

### Time-Discretized Formulations for Scheduling Problems (i)

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *Andreas Bärmann*

#### 1 - Lower Bounds for the Resource-Constrained Project Scheduling Problem from a Time Bucket Relaxation

*Alexander Tesch*

The Resource-Constrained Project Scheduling Problem (RCPSP) is a fundamental problem in scheduling theory and also one of the most challenging to solve in practice. It is well known that time-indexed integer programming formulations for the RCPSP can be solved quite efficiently. However, those models suffer from the large amount of variables and constraints when the time horizon becomes large. Recently, a time bucket relaxation has been presented for the RCPSP (Raidl et al. 2016). In that model, the time horizon is partitioned into a fixed number of generically chosen time intervals while a related time-indexed integer program is solved on this set of time intervals. In our talk, we present several new valid inequalities for the time bucket formulation. The improved relaxation is then solved in a destructive fashion to generate strong lower bounds for the RCPSP. Furthermore, we compare several strategies on how the time partitioning should be performed in order to get quick infeasibility certificates. Our computations are tested on instances of the PSPLIB.

## ■ TB-06

Thursday, 11:00-12:30 - WGS|105

### Social Networks

Stream: Graphs and Networks  
*Parallel session*

Chair: *Marinus Gottschau*

#### 1 - Individualism and collectivism in social dynamics: contact process with stochastic opinion fluctuations in complex networks

*Liudmila Rozanova, Alexander Temerev*

We consider dynamics of a complex system modeling the behavior of a large heterogeneous population. Starting from compartmentalized voter model with two separate time scales for "fast" and "slow" interactions, we augment it with introducing a separate stochastic process, responsible for independent opinion formation. This simple modification leads to emergence of rich variety of behavioral modes (herding behavior/opinion leadership, information cascades, consensus oscillations, opinion polarization etc.), with distinct phase separations in configuration space (i.e. forming a well-defined phase diagram.) Most importantly, introducing spontaneous formation of independent opinion allows for interaction modes where opinion distribution fluctuates indefinitely, instead of always converging to one of possible opinions. Describing and identifying these phases has immediate applications in behavioral analysis of financial markets, opinion dissemination and other complex social modeling problems.



## 2 - Bootstrap Percolation on Degenerate Graphs

*Marinus Gottschau*

We consider  $r$ -neighbor bootstrap percolation on finite graphs, a process which corresponds to the Ising Modell at zero temperature and which can be used to model rumor spreading in (social) networks. The process has been introduced by Chalupa, Leath and Reich in 1979 and has gotten much attention since then. Many different properties of the process and the behavior on a variety of graph classes have been analyzed, some of which we address briefly.

The process itself is defined as follows: Given a graph and an initially infected set of vertices, subsequently, an uninfected vertex becomes infected if it is adjacent to at least  $r$  infected vertices. We are mainly interested in the size of the infected set at the end of the process and shall present a result that bounds the size of the infected set at the end of the process from above for degenerate graphs. Recall that a graph is said to be  $d$ -degenerate if every subgraph contains a vertex of degree at most  $d$ . We prove that our given bound is sharp in the sense that there exist graphs and initially infected sets of vertices which get arbitrarily close to the given bound. Also, our results have some more implications, e.g. give raise to bounds on the size of percolating sets.

## ■ TB-07

Thursday, 11:00-12:30 - WGS|106

### Computational Mixed-Integer Programming 2

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *Ambros Gleixner*

#### 1 - SCIP-SDP: A General-Purpose Solver for Mixed-Integer Semidefinite Programming

*Tristan Gally, Marc Pfetsch, Stefan Ulbrich*

Mixed-integer semidefinite programming (MISDP) has received increasing attention in recent years. MISDPs appear in many applications either by adding combinatorial decisions to problems with natural SDP-formulations or by reformulating combinatorial optimization problems to incorporate stronger semidefinite relaxations. While most solution approaches for MISDPs in the past have been problem specific, we will present a general-purpose solver for MISDPs.

After a short overview of applications of MISDP, we will discuss the applicability of interior-point solvers, focussing on the inheritance of relative interior points in a branch-and-bound tree. Furthermore, we will present recent improvements in SCIP-SDP like propagation techniques and heuristics. Finally, we will show computational experiments detailing the impact of the suggested solving techniques.

#### 2 - Four good reasons to use an Interior Point solver within a MIP solver

*Timo Berthold, Michael Perregaard, Csaba Mészáros*

"Interior point algorithms are a good choice for solving pure LPs or QPs, but when you solve MIPs, all you need is a dual simplex." This is the common conception which disregards that an interior point solution provides some unique structural insight into the problem at hand. In this talk, we will discuss some of the benefits that an interior point solver brings to the solution of difficult MIPs within FICO Xpress. This includes many different components of the MIP solver such as branching variable selection, primal heuristics and preprocessing for linear, quadratic and conic problems.

#### 3 - Current progress in ParaXpress

*Yuji Shinano*

ParaXpress is a distributed memory parallel MIP solver, which is based on the Ubiquity Generator Framework UG. ParaXpress is designed to run numerous instances, in the order of tens of thousands, of the state-of-the-art commercial MIP solver FICO Xpress solvers on a super-computer to solve a single MIP instance. An interesting feature for distributed MIP solving is the one of layered presolving, which was not realized in the first implementation of ParaXpress. We will discuss challenges of and conditions for an efficient implementation of layered presolving in an external parallelization framework and report on the current progress in ParaXpress.

## ■ TB-08

Thursday, 11:00-12:30 - WGS|107

### The Future of Mobility

Stream: Traffic, Mobility and Passenger Transportation  
*Parallel session*

Chair: *Heiko Schilling*

#### 1 - Transforming Mobility – Navigation Technology Past, Present, and Future

*Felix G. König, Heiko Schilling*

Navigation technology is a key building block for mobility. As mobility evolves through technological advances like the connected car, electric vehicles, and autonomous driving, new navigation challenges arise.

Automotive navigation has crucially relied on algorithm engineering from day one. Crowd-sourced floating car data and big data processing have paved the way to extremely accurate historic speed profiles and up-to-the-minute real-time traffic information. Advanced routing algorithms make use of this abundance of data to outsmart traffic and reduce congestion, contributing to more efficient mobility for all.

Today, electric vehicles create new navigation challenges like optimizing routes for consumption and charging stops, or accurately estimating vehicle range based on advanced consumption models. Connected cars becoming the norm have opened up opportunities for more and richer navigation services, like incremental over-the-air map updates, on-street parking assistance, and an increasing level of personalization and contextual awareness in navigation.

Going forward, navigation is a key innovation area on the path towards automated driving. The fusion of sensor-based sub-lane-level positioning and real-time high-definition maps enable the automated vehicle to function safely in its immediate surroundings, but also see beyond its physical sensors. Autonomous driving will also pave the way towards mobility as a service, which will trigger a new wave of algorithmic challenges on the path to next-generation navigation.

#### 2 - Precisely Detect "Object" Locations Using Crowdsourcing and Machine Learning

*Sören Sonnenburg*

Crowdsourcing, i.e., user provided input, is a highly scalable and effective way of involving a userbase to solve out-of-reach tasks. The ubiquity of devices utilizing the Global Navigation Satellite System enables a new kind of user provided input: The reporting of the presence or absence of "objects" at a certain location. Among the numerous examples or such "objects" are coffee shops, but in particular objects relevant to the field of traffic, like speed limit enforcement devices, traffic jams, and road closures to name but a few. Based on such user inputs, the exact localization of the object is hindered by

a) low resolution of the geo coordinates provided by the device / user  
b) inaccurate reports (user selecting wrong location, or reporting when no longer in the vicinity)  
c) adversely reported false locations.

Based on the statistics of a set of such rather noisy user reports in the (not necessarily close) vicinity of the object, a prediction method is presented that accurately and robustly estimates the object's location. In this talk we illustrate how this machine learning based method can be used to detect speed limit camera locations as an example.

#### 3 - Autonomos – Autonomous Driving Technology from Berlin

*Tinosch Ganjineh*

Interest in the subject of autonomous vehicles has vastly increased in recent years and nowadays it is a much discussed topic. Almost all automobile manufacturers are working on solutions of their own. Autonomos is one of the pioneers of self-driving cars, having started in 2007 and, since 2010, carrying out autonomous test drives in city traffic in Berlin.

This talk gives an overview of the technology supporting the sense-plan-act paradigm for autonomous vehicles: Visualization and real-time analysis of a variety of sensor data, calculation of traffic-related decisions by the vehicle itself, and the integration of relevant safety measures.

## ■ TB-09

Thursday, 11:00-12:30 - WGS|108

### MINLP-Methods

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *Oliver Stein*

#### 1 - Solving MIQQP Topology Optimization Problems by Successive Nonconvex Approximation

*Gregoire Njacheun njanzoua, Ivo Nowak*

The Topology Optimization (TO) problem is a basic engineering problem of distributing a limited amount of material in a design space. The finite element formulation of TO is a large scale nonconvex Mixed Integer Quadratically Constrained Quadratic Program (MIQQP) with millions of variables. Traditional methods for MIQQP are branch-and-bound methods, and cannot solve realistic TO problems. Commercial TO solvers can only compute local solutions, which depend strongly on the starting point.

In this talk we present a new decomposition-based global optimization method for TO, which is based on DIOR (Decomposition-based Inner- and Outer-Refinement), a new algorithm for solving MIQQPs and MINLPs by successively refining a nonconvex approximation. We implemented the TO algorithm in Python/Pyomo within Decogo, a new decomposition-based MINLP-solver. Numerical results will be presented.

#### 2 - Hypervolume Maximizing Representation for the Bi-objective Knapsack Problem: The Rectangular Knapsack Problem

*Britta Schulze, Carlos M. Fonseca, Luis Paquete, Stefan Ruzika, Michael Stiglmayr, David Willems*

The cardinality constrained rectangular knapsack problem is a variant of the quadratic knapsack problem. It consists of a quadratic objective function, where the coefficient matrix is the product of two vectors, and a cardinality constraint, i.e., the number of selected items is bounded. In the literature, there are rather few results about the approximation of quadratic knapsack problems. Since the problem is strongly (NP)-hard, a fully polynomial approximation scheme (FPTAS) cannot be expected unless (P=NP). Furthermore, it is unknown whether there exists an approximation with a constant approximation ratio. However, the cardinality constrained rectangular knapsack problem is a special variant for that we present an approximation algorithm that has a polynomial running time with respect to the number of items and guarantees an approximation ratio of (4.5). We show structural properties of this problem and prove upper and lower bounds on the optimal objective function value. These bounds are used to formulate the approximation algorithm. We also formulate an improved approximation algorithm and present computational results.

The cardinality constrained rectangular knapsack problem is related to the cardinality constrained bi-objective knapsack problem. We show that the first problem can be used to find a representative solution of the second problem that is optimal for the hypervolume indicator, which is a quality measure for a representation based on the volume of the objective space that is covered by the representative points. Further ideas concerning this concept and possible extensions are discussed.

#### 3 - Feasible Roundings for Granular Optimization

*Oliver Stein*

We introduce a new technique to generate good feasible points of mixed-integer nonlinear optimization problems which are granular in a certain sense. Finding a feasible point is known to be NP hard even for mixed-integer linear problems, so that many construction heuristics have been developed. We show, on the other hand, that efficiently solving certain purely continuous optimization problems and rounding their optimal points leads to feasible points of the original mixed-integer problem, as long as the original problem is granular. For the objective function values of the generated feasible points we present computable a-priori and a-posteriori bounds on the deviation from the optimal value, as well as efficiently computable certificates for the granularity of a given problem.

Computational examples for several problems from the MIPLIB libraries illustrate that our method is able to outperform standard software. A post processing step to our approach, using integer line search, further improves the results.

## ■ TB-10

Thursday, 11:00-12:30 - WGS|108a

### Branch-and-Price

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *Stefan Irnich*

#### 1 - A Stabilized Branch-and-Price Algorithm for Vector Packing Problems

*Katrin Hebler, Timo Gschwind, Stefan Irnich*

This paper considers packing and cutting problems in which a packing/pattern is constrained independently in two or more dimensions. Examples are restrictions with respect to weight, length, and value. We present branch-and-price algorithms to solve these vector packing problems (VPPs) exactly. The underlying column-generation procedure uses an extended master program that is stabilized by (deep) dual-optimal inequalities. While some inequalities are added to the master program right from the beginning (static version), violated dual-optimal inequalities from exponentially sized families of inequalities are added dynamically. The column-generation subproblem is a multi-dimensional knapsack problem, either binary, bounded, or unbounded depending on the specific packing or cutting problem that is addressed. Its fast resolution is decisive for the overall performance of the branch-and-price algorithm. In order to provide a generic but still efficient solution approach for the subproblem, we formulate it as a shortest path problem with resource constraints (SPPRC), yielding the following advantages: (i) Violated dual-optimal inequalities can be identified as a by-product of the SPPRC labeling approach and thus be added dynamically; (ii) branching decisions can be implemented into the subproblem without deteriorating its resolution process; and (iii) larger instances of higher-dimensional VPPs can be tackled for the first time. Computational results show that our branch-and-price algorithms are capable of solving VPP benchmark instances effectively.

#### 2 - On the Gap of the Skiving Stock Problem

*John Martinovic, Guntram Scheithauer*

The (one-dimensional) skiving stock problem (or SSP for short) represents a combinatorial optimization task being of high relevance whenever an efficient and sustainable use of limited resources is intended. In the classical formulation, given (small) items shall be combined to obtain as many larger objects (specified by some minimum length to be reached at least) as possible. Hence, the SSP can be considered as a natural counterpart of the extensively studied 1D cutting stock problem. However, despite sharing a common structure (e.g. with respect to the input data), both problems are not dual formulations in the sense of mathematical optimization. Therefore, the SSP represents an independent challenge in the field of cutting and packing. As many other problems in combinatorial optimization, the SSP is known to be NP-hard. Due to this observation, (approximate) solution approaches based on LP relaxations and/or appropriate heuristics are of great scientific interest. Among others, their performance mainly depends on the tightness of the considered relaxation, i.e., on the absolute difference (called gap) between the optimal values of the LP relaxation and the ILP problem. While numerical computations suggest that there is always a very small gap, a theoretical verification of this observation is very difficult, in general. After a short introduction to the skiving stock problem, this presentation gives an overview on different approaches and results concerning the gap. Besides considering the general case of arbitrary instances, we mainly focus on the so-called divisible case. Thereby, special emphasis is placed on the development of new and improved lower and upper bounds for the (maximal) gap.

#### 3 - Column Generation for the Soft-Clustered Vehicle-Routing Problem

*Stefan Irnich, Timo Hintsch*

The clustered vehicle-routing problem (CluVRP) is a variant of the classical capacitated vehicle-routing problem in which the customers are partitioned into clusters. It is assumed that each cluster must have been served in total before the next cluster can be served. This presentation considers the CluVRP with soft-cluster constraints (CluVRPSC). Customers of the same cluster must still be part of the same route, but no longer need to be served contiguously. We present an exact branch-and-price-and-cut algorithm, compare different solution methods for the subproblem, and discuss branching strategies and the addition of cutting planes. The subproblem is solved as an elementary shortest path problem with resource constraints by labeling algorithms.

We highlight similarities and differences to pricing for pickup-and-delivery problems. The labeling is supplemented by heuristic strategies for partial pricing. To the best of our knowledge, this branch-and-price-and-cut algorithm is the first exact approach for the CluVRPSC.

#### 4 - A branch-and-price algorithm for the SPP

*Isabel Friedow*

We consider the 2D rectangular strip packing problem (SPP). Given a set of rectangles, the objective of the SPP is to place these rectangles within a strip of given width and unrestricted height in such a way that the strip height needed becomes minimal. A relaxation of this problem is the 1D horizontal bar relaxation (HBR), in which a rectangle is represented by a unit-height item-type with a demand corresponding to the rectangle height. The items are packed into 1D bins and the aim of the HBR is to meet the order demand of all types while minimizing the number of bins used. A solution of the HBR only represents a solution of the SPP if all items of the same type are placed in consecutive bins. In addition to this vertical contiguity condition, also the constant location of item-types has to be ensured, which means, all items representing one rectangle need to have the same x-position in each bin. We investigate a branch-and-price algorithm in which sequences of bins are generated which fulfill the constant location property. To obtain a next bin for a sequence, called successor, we solve the HBR with an additional constraint that ensures the usage of successors with an appropriate usage frequency. This linear problem is solved by column generation and the slave problem related to a successor is modified in such a way that both desired properties, the contiguity and the constant location property, are ensured. We test our approach for different sets of test instances and compare the results with those of other exact methods proposed in literature.

## ■ TB-11

*Thursday, 11:00-12:30 - WGS|005*

### Vehicle Routing - Heuristics I

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: *Katharina Glock*

#### 1 - The Time Dependent Vehicle Routing Problem: A Simulation Based Dynamic Programming Approach

*Mehmet Soysal, Mustafa Çimen, Sedat Belbag, Cagri Sel*

This paper addresses a Time Dependent Vehicle Routing Problem. Dynamic Programming approach is used for formulating and solving the problem. However, the high memory and computation time requirements of large sized instances render the classical Dynamic Programming approach infeasible. We, therefore, propose a Simulation Based Restricted Dynamic Programming approach to solve large sized instances. Computational analyses show the added value of the proposed model and the heuristic approach. According to the numerical experiments the Simulation Based Restricted Dynamic Programming heuristic can provide promising results within feasible computation times for the Time Dependent Vehicle Routing Problem. It has also been observed that incorporating time dependent travel times into decision support models has potential to improve the performance of resulting routes in terms of transportation emissions and travel cost.

#### 2 - Vehicle Routing Problem with Ridesharing and Walking

*Olivier Gallay, Marc-Antoine Coindreau, Nicolas Zufferey*

This work is motivated by the network of a large energy provider, in which the workers have to visit clients at spread locations to perform a variety of small maintenance jobs. In that context, it has been observed that the workers frequently leave their vehicle and perform clustered jobs on foot even if their given planning would recommend to drive to their next jobs. This situation is particularly enhanced in an urban context, where distances between jobs often allow for walking, and furthermore where the traffic is generally congested and parking spots are limited. In order to evaluate the potential benefit offered by such type of multi-modality, we propose a generalization of the static day-ahead Vehicle Routing Problem with Time Windows, where walking between jobs is allowed, and where a car can transport multiple workers. We come up with a dedicated variable neighborhood search that is able to efficiently address this new problem formulation, in particular

when tackling the additional complexity resulting from the appearance of necessary synchronization constraints between the routes. This ultimately allows us to exhibit the potential brought by the introduction of vehicle sharing and walking in the investigated class of routing problems. More particularly, we show that this new formulation helps to substantially reduce both the total transportation costs and the vehicle fleet size, which are the two main objective functions typically considered in Vehicle Routing Problems.

#### 3 - Extensions to the Correlated Orienteering Problem for Emergency Surveillance

*Katharina Glock, Anne Meyer, Guido Tack*

In case of emergencies such as fires involving harmful substances, emergency crews rely on the quick assessment of potentially affected areas. Unmanned aerial vehicles (UAV) are a possibility for providing this information by using remote sensors for surveilling a designated area.

Based on a preliminary image from high altitude, low altitude flights of UAV are planned in a way that as much information as possible is collected within the available flight time. An important aspect during the flight planning is the spatial correlation, which describes the relation of observations at different points and allows making inferences for neighbouring points not visited by the UAV. In literature, this planning problem is modelled as a Correlated Orienteering Problem (COP), which accounts for the spatial correlation in a simplified manner.

In this talk, we propose improved models describing this correlation more accurately based on the observed distribution of the contaminant. Furthermore, we discuss three utility measures relevant for our application: the concentration of a contaminant, high interest points, and the uncertainty about the available information and hence the need to gather more data. For solving our extended versions of the COP, we present a Constraint Programming based Large Neighbourhood Search. Correlation models and utility measures are evaluated using examples from real-world scenarios, notably a use case in firefighting.

## ■ TB-12

*Thursday, 11:00-12:30 - WGS|BIB*

### IBM Business Session – On Deploying successful Decision Optimization applications

Stream: Business Track  
*Parallel session*

Chair: *Sofiane Oussedik*

#### 1 - IBM Decision Optimization cloud offering

*Sebastian Fink*

IBM Decision Optimization on Cloud delivers a compelling, easy, self-service experience to help users harness the power of optimization-based decision support without the install, deployment and maintenance burdens of traditional on premise infrastructures. During this presentation we'll go thru the offering and present an example.

#### 2 - Designing and building new aircrafts case study

*Sofiane Oussedik*

The presentation of the use case will highlight the importance of having the right tools and choosing a good modeling option in order to cover the client's needs. Designing and building a new aircraft is complex and requires to schedule a few millions of activities such as product design, parts design tools design and assembly tasks, we'll discuss the functional needs of such application and how the needs were satisfied.

## ■ TB-13

*Thursday, 11:00-12:30 - RVH|I*

### Smart Services and Internet of Things

Stream: Business Analytics, Artificial Intelligence and Forecasting  
*Parallel session*

Chair: *Maria Maleshkova*

## 1 - Smart Components for Value-driven Service Adaptation

*Maria Maleshkova*

Current market trends, in the context of product as well as service offerings, are characterized by shortening of the lifecycles and increasing demand for customized solutions. Both market competitiveness and new technology developments push companies towards constantly reshaping and improving the organizational, controlling and development aspects of product and services, having individualized customer needs determine not only the final result but also the actual design, development, implementation and delivery process steps, as well as the associated business models. Up to date, the main driving forces behind IT products and services have been the market demand, and the level of technology maturity and innovation. Therefore, the technology has dictated, in a lot of cases, the functionalities and features that are offered to the client. Very little attention has been paid to addressing specific customer value preferences (e.g. customers might require the same product but have very different value needs in terms of, for example, fairness, protection and privacy).

Our work aims address precisely this challenge by bridging the gap between customer value preferences and the technical requirements for a solution. In particular, we make two main contributions - 1) we present an approach for translating user value preferences into technical requirements that can be realized via resources and functionalities that components offer, 2) we show how smart components can be reconfigured and adapted in order to fit the specified values, without modifying the overall implementation of the solution. We use a use case from the predictive maintenance domain as a running example in order to demonstrate the applicability of our approach.

## 2 - Towards Self-governed Smart Services

*Sebastian Bader*

Currently the World Wide Web is shifting from a human-centered towards a more and more machine-processable environment. Especially global trends like the Internet of Things demonstrate how the established principles of the Web provide an infrastructure for basically any kind of information exchange. In addition to traditional, human-oriented websites, an increasing number of Web APIs offer access to functionalities and data, which can be composed to powerful, federated applications. Unfortunately one current limitation is that the integration process is a sophisticated task that requires profound knowledge of the APIs and their specific constraints.

In this context we propose the notion of modular, self-governed Smart Services which, relying on standard Web technologies, can autonomously select and realize actions. Based on the semantic data format RDF, the proposed components consume, manipulate and send both data and program logic in a single consistent manner. Interfaces built on Linked Data standards combine data handling with service invocations, thus, being capable to invoke, trigger and even reprogram each other autonomously and thereby create complex distributed systems.

We present how semantic API descriptions on input and output data, functional and non-functional aspects assist to configure the data exchange between self-governed Smart Services. In order to increase the possibilities to find suitable functionality providers, the Smart Services are enabled to compromise on and even neglect conflicting aspects. Therefore, the outlined components encapsulate aspects of the integration problem and reduce the required manual implementation effort.

## 3 - Optimizing Data Flows in Loosely Coupled Distributed Applications at Runtime

*Felix Leif Keppmann*

Recent developments such as the Internet of Things, Industrie 4.0, and Smart Factories, imply the composition of applications based on a very heterogeneous landscape of components, including both hardware and software. In specific scenarios, components, which are developed and produced by different stakeholders, must be adapted to communicate with each other to provide the overall value-added functionality of the application. While approaches (e.g., the Smart Component approach) enable this adaptation at runtime, based on Web and Semantic Web technologies, we focus in this work on the challenge of self-adaptation within such applications, e.g., to enable the optimization of data flows without external intervention.

With respect to this challenge, we present the following contributions: 1) The concept of a Self-adapting Application based on the Smart Component approach. While the Smart Component approach enables the adaptation of loosely coupled components at runtime, we extend this approach by allowing adjustments between components at runtime, e.g., to enable the optimization of data flows at runtime without

external intervention. 2) The implementation of a Rule-based Optimization by translating a simple mathematical algorithm to rules that can be decentrally deployed within the self-adapting application. The optimization with respect to throughput of data is based on the data producing and data consuming frequencies of the involved components. 3) The Performance Evaluation of a self-adapting application to evaluate the deployment of rules and the rule-based optimization with respect to overhead, throughput, and overall processing frequency.

## ■ TB-14

*Thursday, 11:00-12:30 - RVH|II*

## Airline Revenue Management

*Stream: Pricing and Revenue Management*

*Parallel session*

*Chair: Robert Klein*

### 1 - Optimal Benchmarks for the Revenue Management Problem

*Robert Dochow, Stefan Heuer*

Consider the revenue management problem (RMP) where a seller's objective is to maximize the revenue by selling a homogeneous and perishable product with a limited capacity and a given discrete set of prices. In a market, customers' requests arrive sequentially with a positive willingness to pay. The seller decides on the protection levels which quantify the number of provided pieces for a price to be sold before a next higher price is provided. If the seller knows the exact sequence of the market in advance then the RMP is called offline problem, otherwise it is denoted as online. Current literature describes the offline problem, which has a combinatorial structure, mainly based on worst-case scenarios but a solution for arbitrary sequences of the market is missing. In this paper we provide an algorithm for that offline problem, which allows a practical evaluation of automated revenue management systems. Furthermore, the development of systems without the need of demand forecasts may benefit.

### 2 - A stochastic dynamic pricing model for passenger air transportation

*Fernando Zepeda, Heiko Schmitz*

Dynamically deciding on the ticket prices leverages a substantial gain at a flight and total revenue level. To support these decisions, important elements of modern revenue management systems are the forecast of expected demands and the price optimization for a given seat inventory. This study presents a dynamic pricing model for a single-leg flight without cancellations and no-shows built on the consideration of both elemental parts in revenue management.

We characterize the demand by estimating customer price response and inter-arrival times between two customers that book a ticket. In contrast to the belief that these processes follow a pre-defined stochastic distribution, we support our estimation with the fitting of several families of distributions to its underlying stochastic processes. Relaxing the assumption that inter-arrival times are exponentially distributed opens new possibilities beyond Poisson modelled arrival processes and thus gives flexibility to apply general renewal processes. We choose the best suitable distribution type and calculate its parameters with maximum likelihood estimation. Finally, using the proposed dynamic model, we integrate both forecasting and optimization parts calculating the optimal price trajectory and expected revenue for a particular flight in a real-world case using industry data.

With a flexible description of the arrival and buying behaviours and the evaluation of this input in the dynamic model for the optimal price estimation, an increase of revenue is expected.

### 3 - A Frank-Wolfe Decomposition Approach to Network Revenue Management

*Thomas Winter, Ivo Nowak, Jörg Pancake-Steeg, Stephan Würfl*

In network revenue management, the objective is to optimize the selection of offered products based on demand forecasts and pricing information. The different inventory parts in this network are coupled by constraints arising from the product definitions. Theoretically, the solution of this problem can be computed by a large-scale dynamic programming approach. However, this approach suffers from the curse-of-dimensionality of its very large state space. Even for small networks

the corresponding network optimization problem is computationally intractable.

We present the application of the well-known Frank-Wolfe decomposition scheme to this network revenue management problem. Starting from a reformulation of the problem, we develop the Frank-Wolfe iteration and discuss its convergence for some network instances. The resulting subproblems consist of dynamic programs for each single inventory unit. These dynamic programs can be solved to optimality within a couple of seconds.

As a prerequisite for the decomposition approach, we present a revenue-consistent computation of reconstrained forecasts for each product on each inventory unit. As part of the evaluation of the convergence of our algorithm we discuss the practical interpretation of the scaling factors of the reconstrained forecasts on single unit and network level.

## ■ TB-15

Thursday, 11:00-12:30 - RVH|III

### Modelling and Simulation for Operations and Logistics

Stream: Simulation and Statistical Modelling  
*Parallel session*

Chair: Yony Fernando Ceballos

#### 1 - Integration of Order Acceptance into Optimization-Based Order Release models

*Pia Netzer, Stefan Haussler, Hubert Missbauer*

Attaining short and reliable lead times and at the same time high output and good due-date performance is crucial to remain successful in Make-To-Order (MTO) companies. Hierarchically organized multi-stage workload control (WLC) strategies that introduce the control stages "order release" and "order acceptance" have the potential to attain these requirements. Interestingly, there is no such hierarchical WLC approach that integrates order acceptance into optimization based order release models. We close this gap by developing a new hierarchical WLC concept that combines order acceptance with optimization-based order release and analyze the performance by using a simulation model of a MTO job shop. More precisely, we develop and analyze a hierarchical WLC approach consisting of an optimization based order release model (a clearing function model) and various order acceptance rules as well as an optimization based order acceptance model. Results show that the performance increases when integrating order acceptance into optimization based order release models. Thus, this paper highlights the potential of integrating higher decision levels into optimization based order release models.

#### 2 - Analysis of machine use in sport center in Medellin, Colombia

*Yony Fernando Ceballos, Salomé Naranjo, Carlos Hernandez*

Discreet event simulation was applied on El Molino Sport Center located in Medellin, Colombia. This was done to analyze the difficulties presented there and primarily to find alternatives for the improvement of the performance in the routines designed by personal trainers for the users. It was found that bottleneck machines when more than one routine crosses another and users get limited in their routines due to the congestion in the use of them. A scenario analysis was completed for the efficiency of the service and a routine redesign avoiding machine's intersection. Also, was analyzed the increase of the number of machines, especially Back Pulley and Triceps Pulley with buying and accommodation costs. Finally, we simulate an ideal scenario were people that visit the sport center remove machines weights and leave them in the initial position (without weights). We found that three scenarios were possible, some with less investment than others, but all with the mandatory cooperation of users.

## ■ TB-16

Thursday, 11:00-12:30 - RBM|1102

### CANCELLED: Miscellaneous

Stream: Production and Operations Management  
*Parallel session*

Chair: Gabriel Trazzi

## ■ TB-17

Thursday, 11:00-12:30 - RBM|2204

### Treatment Planning and Health Care Systems

Stream: Health Care Management  
*Parallel session*

Chair: Stefan Nickel

#### 1 - Preventing Hot Spots in High Dose-Rate Brachytherapy

*Björn Morén, Torbjörn Larsson, Åsa Carlsson Tedgren*

High dose-rate brachytherapy is a method of radiation therapy, used in cancer treatment, where the radiation source is placed inside or close to a tumour. In addition to give a high enough dose to the tumour it is also important to spare nearby organs. Mathematical optimization is increasingly used at clinics for dose planning of the treatment, in which the source irradiation pattern is decided. The recommended way to clinically evaluate dose plans is based on dosimetric indices. Such an index quantifies the discretised portion of the tumour that gets at least (or for organs, at most) the prescribed dose.

There are optimization models for dose planning that take homogeneity of the dose into account, but there are none, to our knowledge, that also includes the spatial distribution of the received dose. Insufficient spatial distribution of the dose may result in hot spots, which are contiguous volumes in the tumour that receive a dose that is too high (e.g. more than 200% of the prescribed dose). This aspect is a reason of concern because of risk for complications. With a given dose plan that satisfies the targets in terms of dosimetric indices, a common clinical practice is to inspect the spatial dose distribution before approving the dose plan and if the hot spots are too large, adjust the dose plan.

We study this adjustment process by means of mathematical optimization and introduce criteria that take spatial distribution of dose into account with the aim to spread out or reduce the size of hot spots. This results in large-scale mixed-binary models that are solved using non-linear approximations. We show that it is possible to improve a dose plan in this respect while at the same time maintaining good values with respect to dosimetric indices.

#### 2 - Kidney exchange programs with a priori crossmatch probing

*Filipe Alvelos, Ana Viana*

Kidney exchange programs rely on the definition of pools of incompatible donor-patient pairs and on preliminary information about the compatibilities of donor and patients of different pairs. Assuming some objective, e.g. maximizing the number of transplants, a set of transplants can be planned such that the donor of the pair of a patient receiving a kidney also donates. Commonly, after a transplants plan is defined, actual crossmatch tests are performed for each pair involved in that plan, in order to confirm compatibility between the patients and donors selected for transplant. If the result of the test is positive, it reflects incompatibility and the planned transplant must be canceled, as well as the others transplants involved in the exchange. We discuss a different approach: to conduct actual crossmatch tests before a plan is decided. First, we select a potential transplant and conduct the actual crossmatch test. Based on its result, another potential transplant is selected and the same procedure is repeated. Since conducting crossmatch tests involves time and money, the approach is limited by a maximum number of tests that can be performed. We propose two different methods to decide which pairs should be selected for a priori crossmatch tests and compare results, in terms of transplants performed, with the standard procedure.

### 3 - Evaluating the Performance Criteria of Health Information Systems by Using Fuzzy Type-2 Multi Criteria Decision Making Methodology

Betül Özkan

Health Information Systems help to improve the effectiveness and quality in hospitals. An effective used system will provide many advantages on patients and doctors. There are many different criteria that affect the performance of a health information system. Evaluating these performance criteria is a multi criteria decision making problem. In this paper, the criteria for evaluating the performance of a used health information systems are considered by using fuzzy type-2 Analytic Hierarchy Process (AHP). Type-2 fuzzy numbers are used to deal with uncertain and vague situations. First, the criteria are determined by experts and from the studies in literature and then type-2 fuzzy AHP is applied to determine the weights of main and sub-criteria. These obtained weights will show which criteria have more importance on the performance of the used system and managers in hospitals will evaluate the system according to these criteria.

## ■ TB-18

Thursday, 11:00-12:30 - RBM|2215

### Project Management

Stream: Project Management and Scheduling  
Parallel session

Chair: Matthias Gerhard Wichmann

#### 1 - Impact Assessment Based Sectoral Balancing in Public R&D Project Portfolio Selection Problem

Sinan Gürel, Musa Çağlar

Government funding agencies provide considerable amount of R&D funds through funding programs. While constructing R&D project portfolio, Decision Maker (DM) wants to balance program budget over sectors or scientific disciplines. Existing approaches in the literature assume budget share of each sector is known at the beginning. However, in practice, the DM wants to decide on sectoral budgets. In this study, we incorporate results of so-called "sectoral impact assessments" into public R&D project portfolio selection decisions. We develop a two-stage model. In the first stage, the DM deals with sectoral budget decisions to maximize the total impact of the budget while ensuring relative sectoral budget balances. In the second stage, the DM wants to maximize the total score of supported projects under allocated sectoral budgets. We illustrate proposed approach on an example problem. We show the value of the proposed approach by comparing it with alternative policy options to give managerial insights to the DM.

#### 2 - Success of projects with respect to their characteristics

Arik Sadeh

Success of projects is an important goal for their stack holders. Therefore identification of the causes of projects' success is very attractive. In this study the success of projects was measured and reported using several variables, by project managers and or stack holders. The projects are classified in four dimensions: (i) the level of project's novelty, (ii) the complexity of projects from the management point of view, (iii) the level of technological uncertainty at the beginning of projects, and (iv) the pace of completion of projects. This is in accordance with the diamond approach suggested by Shenhar and Dvir (2007). In the context of the diamond approach the four dimensions are commonly abbreviated to NTCP. The characteristics of 400 projects were measured according to these four dimensions NCTP, where each dimension has 3 or 4 ordinal values. The success levels of those projects with respect to those four dimensions were statistically analyzed using structural equations modeling framework. Certain interest was in innovative projects with high levels of novelty and technological uncertainty.

#### 3 - A new Simulation-based optimization Approach for multi-mode resource-constrained project scheduling problems

Parham Azimi

This research addresses a new model along with the appropriate solving method for a resource constrained project scheduling problem (RCPS) with multiple models for the tasks while the preemption of activities are allowed. To model and solve this NP-hard problem, a new general optimization via simulation (OvS) approach has been developed which is the main contribution of the current research. The OvS connects the solutions of the mathematical model to the simulation model, efficiently. Finally, the best solutions are selected and imported to a genetic Algorithm (GA) as initial population where the optimization process is carried out. The results were tested over several test problems and show the efficiency of the approach not only for this problem but also for many similar combinatorial optimization problems.

#### 4 - A fuzzy robustness measure for the scheduling of commissioned product development projects

Matthias Gerhard Wichmann, Maren Gäde, Thomas Spengler

Due to a considerable degree of uncertainty, the generation of robust schedules for the execution of product development projects is a crucial planning task. In the area of robust project scheduling, one basic option is to apply surrogate robustness measures as estimates of schedule robustness. Although project managers typically possess vague information about activity variations, most surrogate measures neglect this knowledge and are entirely based on deterministic data. In this contribution we therefore present the "fuzzy overlap", that is a surrogate robustness measure which accounts for fuzzy activity duration. We provide a mathematical formulation and embed the fuzzy overlap in a two-stage planning approach for the scheduling of product development projects, which aims at balancing the minimization of project costs as the basic scheduling objective with the maximization of schedule robustness. In a numerical study, we compare the performance of our proposed approach with comparable deterministic surrogate robustness measures. The results indicate that the consideration of fuzzy information enhances schedule robustness compared to the application of traditional deterministic surrogate robustness measures.

## ■ TB-19

Thursday, 11:00-12:30 - RBM|3302

### Scheduling and Workload Control

Stream: Production and Operations Management  
Parallel session

Chair: Seyda Topaloglu Yildiz

#### 1 - Precedence theorems and dynamic programming solutions for the precedence-constrained single machine weighted tardiness problem

Salim Rostami, Stefan Creemers, Roel Leus

Schrage and Baker (1978) proposed a generic dynamic programming (DP) algorithm to tackle precedence-constrained sequencing on a single machine. The performance of their DP method, however, is limited due to memory insufficiency, particularly when the precedence network is not very dense. Emmons (1969) and Kanet (2007) described a set of precedence theorems for the problem of sequencing jobs on a single machine in order to minimize total weighted tardiness; these theorems distinguish dominant precedence constraints for a job pool that is initially without precedence relation. In this paper, we connect and extend the findings of the aforementioned articles to the problem of precedence-constrained single machine scheduling to minimize total weighted tardiness. We develop a framework for applying Kanet's theorems to the precedence-constrained problem. We also propose a DP algorithm that utilizes a new efficient memory management technique for solving the problem to optimality. Combining these two, our procedure outperforms the state-of-the-art algorithms for instances with medium to high network density.

Emmons H (1969) One-machine sequencing to minimize certain functions of job tardiness. *Operations Research* 17(4):701-715.

Kanet JJ (2007) New precedence theorems for one-machine weighted tardiness. *Mathematics of Operations Research* 32(3):579-588.

Schrage L, Baker KR (1978) Dynamic programming solution of sequencing problems with precedence constraints. *Operations Research* 26(3):444-449.

## 2 - An Iterative Matheuristic Approach for the Flexible Tour Scheduling Problem

Seyda Topaloglu Yildiz, Mustafa Avci

Employee scheduling issues are crucial for many service organizations like hospitals, banks, restaurants and airports which encounter variable demand pattern for service during the day and across the days of a specified planning horizon. The main problem addressed in this study is called as the tour scheduling problem which assigns work shifts and work days to employees such that the time-varying customer demand is satisfied with minimum cost. Organizations may implement a variety of flexible scheduling policies to deal with this variable customer demand. Applying flexible shift start times is one of the scheduling policies that may lead to a significant reduction in labor cost. However, this policy may assign work shifts to employees which start at different hours on each working day of the employee. Since the shift start times of an employee may vary a great deal across the working days, shift start time bands should be implemented to reduce the shift start time variations to a certain level. Another policy that can increase the scheduling efficiency is the flexible break assignments. In this policy, break time windows are used to provide flexibility in break time assignments. Additionally, managers may obtain flexibility in employee schedules by including different shift lengths and days-on patterns. The main objective of this study is to develop an iterative decomposition based matheuristic that can solve the TSP covering all of these flexible scheduling policies. The developed algorithm utilizes a working set generation mechanism together with a local search procedure. The performance of the proposed approach is tested on a set of randomly generated problem instances. The proposed approach can provide efficient and effective solutions for the TSP.

## 3 - Comparison between Rule- and Optimization based Workload Control Concepts

Stefan Haeussler, Pia Netzer

An important goal in Production Planning and Control (PPC) systems is to achieve short and predictable flow times, especially where high flexibility in meeting customer demand is required. Besides achieving short lead times, one should also maintain high output and due-date performance. One approach to address this problem is the workload control concept. Within workload control research two directions have been developed largely separately over time: Rule based order release mechanisms which determine the release times of the orders following a set of rules and secondly optimization based models that optimize the order releases for a certain planning horizon with respect to an appropriate objective function. A comparison of the most advanced (and used) order release models from both streams is still lacking. Therefore, this study makes a thorough comparison between the rule based "LUMS COR" (Lancaster University Management School corrected order release) mechanism and the optimization based "clearing function" model. We use a simulation study of a hypothetical job shop that integrates both approaches in a rolling horizon setting. Performance is measured by looking at the resulting inventory levels and the due date performance. Preliminary results show that the optimization model outperforms the rule based mechanism, but with considerably higher computation time.

to be executed level by level, on basis of decentral, aggregate information only. Decentral, deterministic, multi-period linear and non-linear programming models are proposed approximating the first-best benchmark of a central allocation planning with full information. These allocation models have been tested in a rolling-horizon simulation applying rule-based, dedicated consumption. The numerical experiments show in which situations the non-linear allocation model is favourable as compared to the linear one, to a traditional rule-based allocation and to a first-come-first-served policy without preceding allocations.

## 2 - Multi-period demand fulfillment in customer hierarchies with stochastic demand

Maryam Nouri Roozbahani, Moritz Fleischmann

Many firms have a hierarchical sales organization with heterogeneous customer segments. Demand fulfillment allocates the available supply to these hierarchical segments through an iterative process based on aggregated information. Aggregating base customer segments causes a loss of heterogeneity among them which results in non-optimal allocation decisions. In this talk, we address a multi-period version of the demand fulfillment problem in such customer hierarchies. In a multi-period setting, demand uncertainty coupled with heterogeneous backlogging and holding costs further adds to the complexity of the problem. We propose decentralization methods which lead to good allocation decisions while respecting the requirements for information aggregation.

## 3 - New Rules for Allocating Supply in Hierarchical, Push-Based ATP Systems under Stochastic Demand and Service-Level Targets

Konstantin Kloos, Benedikt Schulte, Richard Pibernik

Push-based ATP systems pre-allocate scarce supply to customers with higher importance in order to improve their service levels. To account for the multi-level hierarchal structure of sales organizations, this allocation planning is often not performed by means of a (centralized) optimization-based approach, but through "simple" allocation rules (i.e. "per commit" and "rank based") that can be applied centrally and iteratively (top-down) on each level of the hierarchy. In a setting in which a planner wants to achieve customer-specific service-level targets under stochastic demand, these rules oftentimes lead to significant miss-allocations and detrimental performance. Based on a rigorous analysis of optimal allocation techniques we derive two new allocation rules, called the "hybrid" and the "service-level aggregation" approach, that can reduce the gap to an optimal allocation significantly. Both rules can be applied in a hierarchal setting, and they are still relatively easy to understand and implement. In an extensive numerical study we show that the performance of these advanced rules does not depend on the overall heterogeneity of the customers' service-level targets, but on how customers, and, thus, their service-levels, are structured within the hierarchy. In fact, with two new measures (termed as "within" and "between" heterogeneity), we categorize hierarchies and predict the performance of the "advanced" allocation rules with sufficient accuracy. As the rules lead to good allocations in opposing hierarchy configurations, the "within" and "between" heterogeneity of the hierarchy helps the planner to decide which of the advanced rules should be used or if a "simple" conventional approach is sufficient.

## ■ TB-20

Thursday, 11:00-12:30 - RBM|4403

### Hierarchical Demand Fulfillment

Stream: Supply Chain Management

Parallel session

Chair: Konstantin Kloos

#### 1 - Deterministic allocation models for multi-period hierarchical demand fulfillment

Jaime Cano Belmán, Herbert Meyr

In Make-to-Stock environments with a hierarchical sales organization and heterogeneous customers (i.e. profit-based segmented customers) the optimal matching of available resources (in form of Available-to-Promise - ATP) with demand is a challenging task if resources are scarce. Demand Fulfillment in a first step allocates these scarce resources as quotas to forecasted demand. In a second step, these reserved quotas are consumed (promised) when actual customer orders arrive. In a multi-stage sales hierarchy, this allocation process often has

## ■ TB-21

Thursday, 11:00-12:30 - RBM|4404

### Modelling for Business and Society

Stream: OR in Engineering

Parallel session

Chair: Achim Koberstein

#### 1 - The odyssey from business to research data – ideas, concepts, and obstacles explained on gas network data

Oliver Kunst, Friedrich Dinsel, Sascha Witte, Uwe Gotzes, Thorsten Koch

Reliable data is a corner stone of operational research. In the most simple setting you have a central software system collecting all data needed for your analysis, e.g online stores. But in many other cases the data is provided by different source. Which is error-prone.

We cooperate with the biggest German transport system operator (TSO) of natural gas. Gas networks where partly built when typewriters dominated the offices. Over the years, different software systems

where introduced reflecting the needs of engineers, people planning the gas transport, and traders. So, a variety of data sources and formats have to be matched and may contain fault values and inconsistencies.

The gas flow in complex networks and its simulation is a current research topic. Researchers need data of real gas networks to verify and optimize their gas flow models. An active exchange of data between industry and researchers offers a great potential for both parties. But one could not simply publish the data to encourage interested researchers, since it contains business secrets.

In this paper we address the process of collecting and publishing data from the TSO. We show that inconsistent data does not necessarily mean erroneous data. Furthermore, we develop concepts to alienate the data, but to preserve the scientific relevant content. Our experiences are based on the successful establishment of the gaslib—a library of stationary gas networks with different complexities—and ongoing research to establish a similar case for the non-stationary case with time dependent in- and outflows.

## 2 - Solution Algorithm for Capacity Expansion Problem on Networks

*Takayuki Shiina, Jun Imaizumi, Susumu Morito*

We consider a capacity expansion problem on networks. In our approach, integer and stochastic programming provide a basic framework. We develop a multistage stochastic programming model in which some of the variables are restricted to integer values. Given the distribution of the demand, the problem of minimizing the expected value of the total investment cost is considered. The problem is reformulated as a problem with first stage integer variables and continuous second stage variables. An algorithm based on the Benders decomposition is proposed to solve this problem. After then, the application of the model is considered. In Japan, a few new railway lines were constructed and the abolition of trams continued with the progress of motorization. Considering the declining population, introduction of a new transportation system is being studied in order to consolidate homes and workplaces into the city center in the future, and design a new city. Although it is difficult to construct a new railway or subway, we consider the expansion problem of the existing system which supports the conventional public transport network, and computational results are presented.

## 3 - Using mixed integer programming for the optimal design of water supply networks for slums

*Lea Rausch, John Friesen, Lena Charlotte Altherr, Peter Pelz*

The UN sets the goal to ensure access to water and sanitation for all people by 2030 as one of the Sustainability Development Goals to transform our world. To address this goal we present a combined approach for designing water supply networks in urban settlements by applying mathematical optimization methods. Currently, the UN estimates that 663 million people are still without water and at least 1.8 billion people globally use a source of drinking water that is fecally contaminated. Especially, informal settlements, which in many countries are a defining part of urban areas, are often characterized by the lack of an appropriate water supply. We developed a multidisciplinary approach to design an optimal water supply system for informal settlements within a city. For this purpose, the required information on the slum location as well as size is taken from remote sensing and used as input data for the decision problem. The problem is modeled as a mixed integer problem (MIP) aiming to find a network describing the optimal supply infrastructures. Hereby, we choose between different central and decentral approaches with combined supply by motorized vehicles as well as installed pipe systems. This MIP captures investment as well as operating costs, flow conditions and water need requirements. In addition, primal heuristics are employed to reduce the runtime for solving the MIP. To illustrate the approach, we apply it on a small slum cluster in Dhaka and present our results for a low cost water supply.

## 1 - Comparison of City Sustainability Performances with a Hybrid Fuzzy Multi-Criteria Decision Making Method: A Case Study of Turkey

*Abdullah Yıldızbaşı, Ahmet Çalık, Turan Paksoy*

Due to the rapid development of technology and globalization, more than half of the world's population lives in cities. Increasing urbanization brings with it various environmental problems such as global warming, energy consumption, increasing housing density, exporting wastes, and greenhouse gasses. The importance of green city assessments has become popular for scholars and researchers in many fields. Therefore, cities should be evaluated in terms of various criteria in order to increase the quality of life and sustainability of the environment. The existence of these criteria in the assessment of green cities reveals the need for multi-criteria decision-making tools. This paper proposes a hybrid approach based on fuzzy Analytical Hierarchy Process (AHP) and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) for evaluation of green cities regarding selected criteria such as biodiversity and ecosystem, infrastructure and transportation, use of forestry, agriculture, energy alternatives, and buildings. Fuzzy AHP method is applied to obtain the weight of criteria according to different decision makers' judgments. Decision makers consist of city planners, academicians and experts from municipalities and Turkish ministry of environment and urbanization. Then, TOPSIS method is applied for ranking cities by using the weights obtained from fuzzy AHP method. A case study on the sustainable green city performance evaluation of top 10 crowded cities in Turkey is implemented. A comparative analysis was carried out by evaluating the sustainability performances of these cities with the developed approach.

## 2 - From Right to Reality: The Children's Daycare Planning Problem

*Catherine Cleophas, Martin Weibelzahl, Christina Büsing*

As one of the current social challenges in Germany, a well-organized provision of families with daycare adds a high value to the community by enhancing social mobility, the integration of migrants, and equal employment opportunities for women. Despite its importance, an efficient planning of daycare has not been the focus of operations research in the past. For this reason, the present paper explicitly deals with the current problems associated with daycare planning by proposing a first model for a centralized matching process. We assume different daycare facilities that employ nurses, who differ in the types of group constellations that they can supervise. On the one hand, our childcare allocation problem comprises the assignment of nurses to rooms of the daycare facilities with a corresponding group constellation. On the other hand, both existing and applying children must be assigned to one of the available nurses. This assignment accounts for various bounds on rooms, on group constellations, and on daycare facilities. Our centralized daycare planning maximizes the overall satisfaction of families with the assignment, which is measured by the aggregated valuations of the facilities from the perspective of families. In a second step, we address the problem of symmetric solutions of our daycare planning model. Symmetry arises, as in practice many nurses will have similar characteristics that allow them to supervise identical group constellations. In particular, we present a reformulated version of our model that circumvents solution symmetries.

## 3 - Economics of Crisp and Intuitionistic Fuzzy Information

*Olga Metzger, Thomas Spengler, Tobias Volkmer*

The evaluation of the economic benefit of information and the corresponding considerations of (not) obtaining it is one of the most important requirements when making economically rational decisions, not least in the area of knowledge management. A common approach to analytical information assessment (see, for example, Emery, 1969 and Laux, 1979) is based on Bayesian statistics (processing crisp values). Basically, the gross information value is determined by the difference between the expected profit of the decision with additional information (without information costs) and the expected profit without information. In this paper, we present and discuss variations of the information valuation approach according to Emery in the version of Laux. In this context, we analyze the role of a possible negative information value, its ex post evaluation as well as its significance for the rationality of decisions. Additionally, the relevance of harmful information and its impact on the information value are discussed. Whereas traditional approaches for information valuation deal with crisp beliefs regarding the prediction of states of nature and further elements of the decision field, we also want to take account of the vagueness of information by using instruments from the LPI theory and the intuitionistic fuzzy set theory.

## ■ TB-22

Thursday, 11:00-12:30 - HFB|A

### MCDM 4: Multi-Criteria Decision Making and Fuzzy Systems

Stream: Decision Theory and Multiple Criteria Decision Making

Parallel session

Chair: Olga Metzger



References: Emery, J. C. (1969). *Organizational Planning and Control Systems: Theory and Technology*. New York, NY: Macmillan. Laux, H. (1979). *Grundfragen der Organisation - Delegation, Anreiz und Kontrolle*. Berlin: Springer.

## ■ TB-23

Thursday, 11:00-12:30 - HFB|B

### Tropical Geometry and Game Theory (i)

Stream: Game Theory and Experimental Economics  
*Parallel session*

Chair: *Michael Joswig*

#### 1 - Tropical spectrahedra and mean payoff stochastic games

*Stephane Gaubert, Xavier Allamigeon, Mateusz Skomra*

One of the basic algorithmic questions associated with semidefinite programming is to decide whether a spectrahedron is empty or not. It is unknown whether this problem belongs to NP in the Turing machine model, and the state-of-the-art algorithms that solve this task exactly are based on cylindrical decomposition or the critical points method. We study the nonarchimedean analogue of this problem, replacing the field of real numbers by the field of Puiseux series. We introduce tropical spectrahedra, defined as the images by the valuation of spectrahedra over the latter field, or as “log-limits” of spectrahedra over the reals. We show that the elements of tropical spectrahedra can be identified to the potentials (winning certificates) of stochastic mean payoff games. This allows us to apply mean payoff games algorithms to nonarchimedean semidefinite programming.

#### 2 - Mean Payoff Games in Products of Simplices

*Georg Loho*

It is known that finding a winning strategy in a mean payoff game, a feasible schedule for an and-or-network or a feasible point for a tropical polyhedron are polynomial-time equivalent. These problems are in NP and in co-NP but no polynomial algorithm has been found what makes them particularly interesting.

On the other hand, the combinatorics of a tropical polyhedron can be expressed as a subdivision of a product of two simplices. Equivalently, it can be described by a set of bipartite graphs which are composed of minimal matchings.

Combining the geometric point of view with the algorithmic problem allows us to consider a generalization of the feasibility problem. We present a method to solve the feasibility problem in the generalized setting. The algorithm is even pseudo-polynomial when applied to the original setting. This gives new insights in the structure of the problem and connects it with methods from combinatorial geometry.

#### 3 - Tropical Geometry and Mechanism Design

*Robert Crowell*

In economic theory, mechanisms serve as game theoretic models of abstract institutions e.g. auctions, voting procedures and contracts. We will discuss the basic terminology from mechanism design theory, focusing in particular on auctions. We will then introduce some tools from tropical convex geometry and tropical combinatorics that can be used to study such problems in a unified way. The talk will be based on joint work with Ngoc Tran.

## ■ TB-24

Thursday, 11:00-12:30 - HFB|C

### Nonlinear Optimization 2

Stream: Control Theory and Continuous Optimization  
*Parallel session*

Chair: *Maksim Barketau*

#### 1 - Strong Stability of degenerated C-stationary points in MPCC

*Daniel Hernandez Escobar, Jan-J Ruckmann*

We consider Mathematical Programs with Complementarity Constraints (MPCC). The study of strong stability of C-stationary points plays a relevant role in sensitivity analysis and parametric optimization. In 2010, H. Jongen et al. characterized the strong stability of C-stationary points for MPCC under the assumption that the Linear Independence Constraint Qualification (LICQ) holds. Here, we focus on the characterization of strong stability of C-stationary points when LICQ does not hold. We provide an upper bound on the number of constraints as a necessary condition for strong stability as well as a lower bound when a Mangasarian-Fromovitz-type constraint qualification does not hold. We introduce a weaker constraint qualification which turned out to be necessary for strong stability.

#### 2 - Maximization of homogeneous polynomials on the simplex: structure, stability, and generic behavior

*Faizan Ahmed, Georg Still*

The presentation describes maximization of homogenous polynomial over a unit simplex. Optimality conditions and stability properties are described. Maximization of homogenous polynomial over a unit simplex is known to link with evolutionarily stable strategy from biology. We show that generically any local maximizer is a stable ESS.

#### 3 - Quadratic support functions in quadratic bilevel programming

*Oleg Khamisov*

We consider bilevel problem in the following formulation. The follower problem is a convex quadratic problem which linearly depends on leader variable. The leader problem is a quadratic (not necessarily convex) problem. We are looking for an optimistic solution. Optimal value function of the follower problem is used to reformulate bilevel problem as a standard (one-level) optimization problem. By this way we obtain nonconvex multiextremal problem with implicit nonconvex constraint generated by the the optimal value function. We show how to construct explicit convex quadratic function which is support to the optimal value function at a given point. Usage of the support functions allows us to approximate the implicit one-level problem by a number of explicit nonconvex quadratic problems. In our talk we describe an iterative procedure based on such approximation. This procedure generates a sequence of auxiliary solutions every accumulation point of which gives a solution to the initial bilevel problem. Auxiliary solutions are obtained as optimal solutions of auxiliary explicit quadratic problems. We give a detailed description of the suggested approach and provide preliminarily results of numerical experiment. By its nature the suggested approach is a branch and bound approach.

## ■ TB-25

Thursday, 11:00-12:30 - HFB|D

### Maintainance in Energy

Stream: Energy and Environment  
*Parallel session*

Chair: *Philipp Hauser*

#### 1 - An Optimization Model to Develop Efficient Dismantling Networks for Wind Turbines

*Martin Westbomke, Jan-Hendrik Piel, Michael H. Breitner, Peter Nyhuis, Malte Stonis*

In average, more than 1,275 wind turbines were installed annually since 1997 in Germany and more than 27,000 wind turbines are in operation today. The technical and economic life time of wind turbines is around 20 to 25 years. Consequently, dismantling of aging wind turbines will increase significantly in upcoming years due to repowering or decommissioning of wind farms and lead to millions of costs for operators. An option to supersede the costly and time-consuming dismantling of wind turbines entirely on-site is to establish a dismantling network in which partly dismantled wind turbines are transported to specialized dismantling sites for further handling. This network requires an optimization model to determine optimal locations and an appropriate distribution of disassembly steps to dismantling sites. The challenge is to consider the network's dependency on

the trade-off between transportation and dismantling costs which in turn depends on the selection of dismantling depths and sites. Building on the Koopmans-Beckmann problem, we present a mathematical optimization model to address the described location planning and allocation problem. To permit a proof-of-concept, we apply our model to a case-study of a selected region in Northern Germany. Our results show that our model can assist wind farm operators to arrange efficient dismantling networks for wind turbines and to benefit from emerging economic and logistical advantages.

## 2 - On generating a fleet composition for offshore wind farm maintenance operations

*Eligius M.T. Hendrix, Alejandro Gutierrez Alcoba, Inmaculada Garcia Fernandez, Dag Haugland, Elin E. Halvorsen-Weare, Gloria Ortega*

The offshore wind energy industry is expected to continue its growth tendency in the near future. The European Wind Energy Association expects in its Central Scenario by 2030 a total installed capacity of 66 GW of offshore wind in the UE. Offshore wind farms (OWFs) are large scale infrastructures, requiring maintenance fleets to perform operations and maintenance (O&M) activities in the installed turbines. Maintenance gives a major costs of running an OWF installation.

Optimising the efficiency of the resources used for the O&M activities of an OWF, requires an adequate estimate of the costs involved in the maintenance scheduling. However, this scheduling, typically depends on the weather circumstances. We first show a deterministic model formulation that is based on scenarios. As no future events can be used as input information, our question is how scheduling heuristics may provide a better estimate of the maintenance costs and what is the consequence of that for the fleet composition. This paper has been supported by The Spanish Ministry (TIN2015-66680), in part financed by the European Regional Development Fund (ERDF).

## 3 - On a design of economically near optimal nuclear fuel reload patterns

*Roman Cada*

The talk deals with the problem related to the design of nuclear fuel reload patterns. It is basically a multi-criteria nonlinear combinatorial problem, where values of many goal function are obtained by solving huge systems of differential equations by using a suitable discretisation.

A nuclear reactor operates in cycles. Usually every year a part of burned-up fuel is exchanged by fresh one. A basic task is to find a set of fresh fuel assemblies among admissible fuel types to fit the given schedule (duration of cycles) provided the use of fuel during each cycle is as economical as possible.

The schedule of outages is usually planned a few years beforehand. We will distinguish an equilibrium schedule for theoretical conclusions useful for some practical considerations and planning and a typical real world schedule where cycles are not of equal length. We point out potential problems for optimisation methods arising in real world scenarios.

In the talk we present a typical workflow during the design of a sequence of near-optimal nuclear fuel reloading patterns. We focus on the problem of obtaining close to optimum sequences of reload patterns to fit the given scenario of outages within a time available during an outage.

In this article, we study inventory decisions in a multi-period newsvendor model under rational and behavioral assumptions. In particular, we analyze how two different incentive schemes affect ordering decisions: cash-flow and accounting profit. We derive optimal inventory policies for both schemes and find that the order-up-to levels for the accounting profit incentive are greater than or equal to the order-up-to levels for the cash flow incentive. Further, we show that the optimal order-up-to levels for the cash flow incentive decrease toward the end of the planning horizon. Next, we test both incentive schemes in a laboratory environment. We find that the subjects have higher-than-optimal order-up-to levels in the first period. We link this to an underweighting of the holding cost and an overweighting of future sales opportunities. In the second period, subjects have lower-than-optimal order-up-to levels. As a result, we observe an inverse inventory hockey-stick effect that is based on both the incentive schemes and behavioral biases of inventory managers.

## 2 - Explanatory Power of Experience Weighted Attraction in Individual Decision Making Compared to Simple Decision Rules - a Simulation Study

*Heike Schenk-Mathes, Christian Koester*

Experience weighted attraction (EWA) (Camerer and Ho 1998) combines reinforcement learning with fictitious play models and has proven to perform well as an explanatory model in economic experiments on individual decision making (cf. Bostian, Holt and Smith 2008; Köster and Schenk-Mathes 2016), especially in explaining experimental data on the newsvendor problem. Yet, EWA is a relatively complex model with a rather large number of free parameters and includes characteristics of simpler decision models, which might explain its good performance on laboratory data in the past. We present a simulation study which uses different models (including EWA) to generate order decisions in a newsvendor setting. Next, maximum likelihood estimations of these models are executed on the generated data and the fit of the models is evaluated using information criteria. Attention is focused on the performance of EWA. Furthermore, we present analyses on the parameter mix of EWA if more parsimonious models or a mix of these simpler models are used. Hereby, a deeper understanding about the explanatory power of EWA and its eligibility as a model for individual decision making is gained.

## 3 - Should the Retailer or Supplier Exercise Effort to Increase Demand?

*Anna-Lena Sachs, Yingshuai Zhao, Ulrich Thonemann*

Demand promotion activities, such as advertisements, enlarge market size and accordingly increase sales profit. In a supply chain, promotion activities can be exercised by any echelon member. We consider a supply chain which is composed of two members, a supplier and a retailer. We investigate whether the supplier or the retailer should exercise the effort of demand promotion activities. We conduct laboratory experiments and compare supply chain performance for retailers or suppliers exercising effort under a Stackelberg game framework or a negotiation framework.

## ■ TB-26

Thursday, 11:00-12:30 - HFB|Senat

### Behavioral Inventory Management (i)

Stream: Game Theory and Experimental Economics

Parallel session

Chair: Michael Becker-Peth

#### 1 - Inventory Management with Alternative Myopic Incentive Schemes: Rational and Behavioral Decision Making

*Michael Becker-Peth, Kai Hoberg, Margarita Protospappa-Sieke*

## Thursday, 13:30-14:15

### ■ TC-22

Thursday, 13:30-14:15 - HFB|A

#### Semi-Plenary Meinolf Sellmann

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: *Stefan Lessmann*

##### 1 - Meta-Algorithms

*Meinolf Sellmann*

Meta-algorithmics is a subject on the intersection of learning and optimization whose objective is the development of effective automatic tools that tune algorithm parameters and, at runtime, choose the approach that is best suited for the given input. In this talk I summarize the core lessons learned when devising such meta-algorithmic tools.

### ■ TC-23

Thursday, 13:30-14:15 - HFB|B

#### Semi-Plenary Hans-Georg Zimmermann

Stream: Semi-Plenaries

*Parallel session*

Chair: *Ralph Grothmann*

##### 1 - Data Analytics, Machine Intelligence and Digitalization at Siemens

*Hans Georg Zimmermann*

Data Analytics, Artificial Intelligence and Digitalization are general megatrends in research and industry. The big data trend was initiated by the increasing computer power and the internet. But data alone are only information about the past, we have to find structures and causalities between the variables. Based on such models we can compute information about possible futures and go on to decision support or control. The view of artificial intelligence is to solve the above problems with human analog methods. Especially neural networks and deep learning play an important role in such an effort. Siemens has a focus on technical and not internet applications, so we call our development machine intelligence instead artificial intelligence. Finally, digitalization describes the way from physical processes (and production lines) to virtualization, using the digital copy of the processes for optimization and online control.

In a final part of the talk I will show in form of examples, that in an industrial research center research plays an important role: First, we have to confront problems which were unsolved otherwise. Second, the knowledge accumulation in lasting teams opens unique selling points for the company.

### ■ TC-24

Thursday, 13:30-14:15 - HFB|C

#### Semi-Plenary Alexander Martin

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: *Martin Skutella*

##### 1 - Network Flow Problems with Physical Transport

*Alexander Martin*

Looking at network flow problems from a combinatorial point of view the flow is typically assumed to be constant in time and flows without additional requirements such as pressure differences. This is no

longer true if we look at energy networks such as water or gas networks. To appropriately model the physics of these flows partial or at least ordinary differential equations are necessary resulting even in simplified settings in non-linear non-convex constraints. In this talk we look into the details of such models, motivate them by problems showing up in the transmission of the energy system and present first solution approaches with many hints to future challenges.

### ■ TC-25

Thursday, 13:30-14:15 - HFB|D

#### Semi-Plenary Arne Strauss

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: *Catherine Cleophas*

##### 1 - Last Mile Logistics

*Arne Karsten Strauss*

Last-mile logistics providers are facing a tough challenge in making their operations sustainable in the face of growing customer expectations to further decrease lead times to same-day or even same-hour deliveries, and/or to offer narrow delivery time windows. The providers respond to this challenge by investing in their analytic capabilities to make their last mile logistics are efficient and intelligent as possible.

In addition, innovative and disruptive business models are currently on trial, e.g. asset-lean start-ups use crowdsourced drivers or drivers on demand-dependent contracts. Several companies are experimenting with delivery drones or robots, and how to collaborate with each other ('shared economy').

Many of these developments entail exciting new challenges for operations researchers. In this talk, I will review some of the most recent developments and reflect on future research directions.

# Thursday, 14:45-16:15

## ■ TD-01

Thursday, 14:45-16:15 - WGS|101

### Applications of Uncertainty

Stream: Optimization under Uncertainty  
*Parallel session*

Chair: *Christine Markarian*

#### 1 - Influence Maximization with Deactivation in Social Networks

*Kübra Tanınmış, Necati Aras, I. Kuban Altinel*

Influence Maximization Problem (IMP) is one of the prominent problems in social network analysis. It is defined as selecting an initial set of  $k$  nodes in a social network such that the total number of affected nodes is maximized at the end of the influence spread. In this study, a competitive version of IMP, a Stackelberg game on a social network is considered. The leader of the game tries to maximize its influence spread by selecting a set of influential nodes and the follower tries to minimize the leader's influence by deactivating a subset of the influential nodes. The deactivated nodes cannot affect their neighbors, nor they spread an opposite idea or information. As is the case with all Stackelberg games, it is assumed that the follower has complete knowledge about leader's decisions. Once the leader and the follower make their decisions, the influence propagates according to the well-known Linear Threshold (LT) diffusion model until no more nodes can be affected. The problem is modeled as a stochastic bi-level integer programming formulation. To deal with the uncertainty in the node threshold parameter of the LT diffusion model used in the lower level problem, a three-stage sample average approximation (SAA) scheme is implemented. To solve the bilevel model, we propose a matheuristic method. Namely, a simulated annealing heuristic is applied to perform search in the solution space of the upper level problem (i.e., the selection of the influential nodes). Then for each candidate solution generated for the upper level problem an SAA procedure is implemented in the lower level problem to find the optimal set of deactivated nodes which constitutes the optimal response of the follower.

#### 2 - Decision support for tactical planning of maintenance activities - a use case for the INFRAALERT project

*Ute Kandler, Axel Simroth*

The on-going H2020 project INFRAALERT aims to provide Infrastructure Managers with IT tools to support the decision-making process when planning maintenance activities and interventions. In this talk we will focus on the application of the INFRAALERT decision support toolkit to a road pilot from Infraestruturas de Portugal (IP), where we concentrated on the tactical planning level. In this pilot, the decision maker has to allocate major interventions over a 5-year time horizon. The interventions are aggregated as single events over 500m-segments of certain road sections to avoid multiple traffic interruptions on the same section. The monthly allocation of interventions include: i) The allocation of a starting month for intervention events. ii) The selection of a limit for the minimum degradation level for a section. Further, several restrictions e.g., not falling below a certain quality level, meeting budget restrictions or capacity limits for supervisory staff, has to be satisfied. We aim to optimize simultaneously the costs, the quality index and the availability of the network. The allocation and selection of interventions is based on alerts generated by the INFRAALERT Alert Management toolkit, which depends on predicted future conditions resulting from the Asset Condition toolkit. Thus, the input for the decision support are no concrete work orders but predicted work orders and the corresponding probabilities of occurrence. Due to this uncertainty the tactical planning problem becomes a stochastic optimization problem, that calls for specific modelling and solution techniques. The corresponding mathematical optimization model and the handling of uncertain information realized via a scenario approach will be subject of the talk.

#### 3 - Online Leasing with Penalties

*Christine Markarian*

Online Leasing with Penalties

We study online leasing problems in which clients arrive with time and need to be served by leasing resources at minimum possible costs.

There are  $K$  different lease types each with a different duration and price: a longer lease costs less per unit time. Online leasing problems studied thus far assume that all clients need to be served. In practice, this is not always true: e.g., a client arrives on a day that is not profitable to lease a resource. In this work, we introduce an online leasing variant in which a client need not be served as long as a penalty associated with it is paid. We also study a variant in which each client has a deadline and can be served any day before its deadline as long as for each delayed day a penalty is paid: no penalty is paid if served on the day of arrival. In an earlier work, we studied a special case in which no penalty costs are incurred as long as the client is served within its deadline (i.e., all penalties are set to 0). The goal is to minimize the total cost of purchased leases and penalties paid. Should we know the sequence of clients in advance, the two problems (offline version) can easily be solved optimally using Dynamic Programming. Nevertheless, the clients are only revealed to us with time and so we seek algorithms that provide provably good solutions without knowing the future (online version). We give deterministic online primal-dual algorithms, evaluated using standard competitive analysis in which an online algorithm is compared to the optimal offline algorithm which is optimal and knows the entire sequence of clients in advance.

## ■ TD-02

Thursday, 14:45-16:15 - WGS|102

### Deployment of Optimization Models

Stream: Software Applications and Modelling Systems  
*Parallel session*

Chair: *Franz Nelissen*

#### 1 - Developing optimization web apps with Xpress

*Johannes Müller, Susanne Heipcke, Yves Colombani*

FICO Xpress Mosel, originally designed as a modelling, solving and programming language for working with the Xpress Solvers, has gradually been extended to support parallel and distributed computing, going along with a host of new data connectors (including the possibility to act as HTTP client or server), interfaces to tools such as the analytics suite R, and additional solvers for non-linear and constraint programming. The deployment options (cloud, on premises, desktop) of Mosel programs via a web-based multi-user interface find increasing use in large-scale projects, including from non-optimization users. A prominent example is the recently released FICO Decision Optimizer 7.0 that has been fully re-implemented with Mosel. It integrates various analytic components such as decision trees, scorecards and decision impact models. We shall comment on recent enhancements to the Mosel environment, including improved general programming capabilities (remote debugging, code coverage, definition of metadata via annotations) and new language features (e.g. access to Amazon S3 buckets), and demonstrate the new web-based development environment for model and web-application development, including its deployment and debugging capabilities for optimization web apps.

#### 2 - Recent Advances for Building and Deploying Analytical Solutions using AIMMS

*Ovidiu Listes*

We present recent developments in the AIMMS software platform which facilitate a fast and flexible building of analytical decision applications as well as their deployment in enterprise wide systems with client-server architectures and advanced user interfaces.

#### 3 - A distributed Optimization Bot/Agent Application Framework for GAMS Models

*Franz Nelissen*

In this talk we will present a prototype of an optimization bot/agent application framework for GAMS models based on the GAMS .NET API. After the introduction we will show the basic architecture, features and the different elements of the system and illustrate them through an example.

## ■ TD-03

Thursday, 14:45-16:15 - WGS|103

### Railway Transportation

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: Carsten Moldenhauer

Chair: Ronny Hansmann

#### 1 - Complexity of railway freight shunting - overview and new results

Ronny Hansmann

Railway freight shunting is the process of forming departing trains from arriving freight trains in rail yards. The shunting procedure is complex and rail yards constitute bottlenecks in the rail freight network, often causing delays to individual shipments. Planning for the allocation of tracks at rail yards is difficult, due to limited resources (tracks, shunting engines, etc.). The required schedules highly depend on the particular infrastructure of the rail yard, on the configuration of inbound and outbound trains, and on the business objectives. Thus, optimization tools as active decision support for the dispatchers have to be tailored to the actual processes. In this talk, an overview of complexity results for several variants of the underlying Classification Problem is given that stem from fruitful relations to graph coloring, sequence partitioning, and scheduling. We focus on new complexity results for variants that allow a maximum degree of freedom for outbound car moves. Finally, we briefly mention how to compute optimal schedules and we outline the need for future research.

## ■ TD-04

Thursday, 14:45-16:15 - WGS|104

### Network Flows

Stream: Graphs and Networks  
*Parallel session*

Chair: Horst W. Hamacher

#### 1 - Shortest Path Approach to the Min-Max Integer Minimum Cost Flow Problem

Anika Kinscherff, André Chassein

We consider a robust version of the integer minimum cost flow problem (IMCF) with uncertainty in the cost function. It is known that in general this problem is NP-hard. Hence, we restrict our research to a discrete scenario set with a fixed number of scenarios and fix the flow value  $F$  that needs to be sent over the network. For acyclic graphs we present a pseudopolynomial procedure to solve the min-max IMCF. We show that, given the original network  $G$ , we can construct a new network  $H$  deduced from  $G$  and flow value  $F$ , such that every flow in  $G$  can be transformed into a path in  $H$  and vice versa. Since this transformation works in both directions, it is sufficient to solve the min-max shortest path problem in the new network  $H$  to obtain a solution for the original problem. For this task we use a multiobjective label setting algorithm which could output all efficient paths. Among those an optimal solution of the min-max shortest path problem can be found. Further, we reduce the computational effort of the label setting algorithm by including a problem specific dominance criterion.

#### 2 - On Finding Maximum Minimum Cost Flows

Kai Hoppmann, Robert Schwarz

Consider the following problem setup: Given a flow network with arc lengths and lower and upper bounds on the supply values for the sources and the demand values for the sinks. The goal is to determine supplies and demands respecting these bounds, such that the optimal value of the induced Minimum Cost Flow Problem is maximized.

In this talk, we discuss properties of this problem and introduce a linear bilevel optimization model. We present an application in the context of the generation of severe transport scenarios for gas transmission networks, so-called stress tests. Further, we report on computational experiments conducted on a real-world gas network and present future extensions of the problem formulation and the corresponding application.

#### 3 - Swapping all-pair shortest path and maximal flow matrices: Theory and applications

Horst W. Hamacher

Given a network  $(V,E; u,c,b)$  with node set  $V$ , arc set  $E$ , capacity and cost function  $u$  defined on the arcs, and weight function  $b$  defined on the nodes, the following two all-pair matrices are well-known. The all-pair shortest path matrix  $D$  and the all-pair maximal flow matrix  $F$ , where  $(i,j)$ -th entry is the length of a shortest path between nodes  $i$  and  $j$ , and the value of a minimal cut separating nodes  $i$  and  $j$ , respectively. All-pair matrices play an important role as subproblems in more complex optimization models, have various applications (for instance, in locational analysis and transportation planning) and can be computed in polynomial time. In this presentation, we consider optimization problems in which the roles of all-pair shortest path and min-cut matrices are swapped. In this way we obtain, for instance, network location problems with min-cut distances and source location problems in which the network flows are replaced by network tensions. We will discuss properties and solution methods for the new network models and show their potential as modeling tool for real-world problems.

## ■ TD-05

Thursday, 14:45-16:15 - WGS|104a

### Scheduling Problems

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: Cor Hurkens

#### 1 - Location-Scheduling Model to Design Charging Infrastructure for a Fleet of Electric Vehicles

Lubos Buzna, Michal Váňa, Michal Kohani, Matej Cebecauer, Peter Czimmermann

We propose an MIP model to design a private charging infrastructure for a fleet of electric vehicles operating in large urban areas. Examples of such a fleet include taxicabs and small vans used in the city logistics or shared vehicles. The fleet is composed of vehicles equipped with an internal combustion engine, but the operator is wishing to replace them with fully electric vehicles in the near future. It is required to design a private network of charging stations that will be specifically adjusted to the operation of the fleet. We use GPS traces to characterize actual travel patterns of individual vehicles. We formulate a location-scheduling optimization model that determines the maximum number of vehicles that can be recharged without affecting their routes and parking behaviour and finds the corresponding design of the charging infrastructure. The model assumes that all vehicles possess complete information about all other vehicles. To study the role of available information, we evaluate the resulting designs considering coordinated charging when vehicle drivers reveal to each other departure times, and uncoordinated charging when vehicle drivers know only actual occupation of charging points.

#### 2 - MIP and Heuristics for Multi-Earth-Observing Satellites Scheduling

Xiaoyu Chen, Gerhard Reinelt, Guangming Dai

We address a problem of multiple satellites scheduling with limited observing ability, which is a highly combinatorial problem due to the large search space for potential solutions. By preprocessing the problem, we cope with some constraints, thus the input of the problem are only the available resources, the requested missions and the eligibility of resources for missions. We first construct a mixed integer programming (MIP) optimization model for the problem and solve it with Gurobi. On one hand, after analyzing the distribution features of the available time windows of missions, we investigate two-stage heuristics in generating optimal feasible solutions. The first stage involves the determination of observing sequence and the generation of feasible schedule scheme. We develop the time-based and weight-based Greedy algorithms. The second stage is some further improvement strategies facing different resource contentions, thus prevent results from trapping into local optimum. On the other hand, we develop a priority-based and conflict-avoid differential evolution (DE) algorithm for solving it. For the problem, we design several different kinds of instances to test the efficiency and applicability of the algorithms. According to the simulation results, we can figure out that the Gap between the optimal results and solutions solved with algorithms proposed in this paper. The improved DE algorithm shows a significant

advantage in most cases, especially, when the missions are distributed centralized and the resources are over occupied. The improved weight-based Greedy algorithm is also contributed when the problem is less constrained. The experiments verify the correctness and efficiency of this scheduling model, indicating that the constructed algorithms are feasible.

### 3 - Solving integer programming models for the mid-term production planning of high-tech low-volume industries

*Joost de Kruijff, Cor Hurkens, Ton de Kok*

We studied the mid-term production planning of high-tech low-volume industries. We developed two integer programming models to allocate resources to the production of different products over time and coordinate the associated inventories and material inputs such that demand is met. The models support general supply chains, multiple production modes and semi-flexible capacity constraints. The first model assigns resources explicitly, but scales poorly because of the number of constraints. The second model doesn't assign resources explicitly and is solved by a branch and cut method based on Benders decomposition, which uses a maximum flow problem to find feasibility cuts. Our goal is to solve these problems as fast as possible.

In this talk, we will present a number of improvements on the above mentioned solving methods. Among others, we will discuss the impact of having integer or continuous inventory variables. Furthermore, we will investigate the information contained in the maximum flow to find more valuable constraints.

## ■ TD-06

*Thursday, 14:45-16:15 - WGS|105*

### Demand and Load Balancing in Networks

Stream: Graphs and Networks

*Parallel session*

Chair: *Christoph Helmberg*

#### 1 - Predictive Analytics Based Energy Pricing Approach for Smart Grids

*Jan Keidel, Peter Gluchowski*

Because of the transition towards sustainable energy, the availability profile of energy changes drastically. By using decentralized renewable energy sources such as solar energy, wind energy or hydroelectricity it is much more difficult to compensate regional and temporal differences in energy generation and consumption in smart grids.

With the help of advanced information and communication technologies (ICT), different energy management techniques such as dynamic pricing schemes, forecasting of energy load and generation as well as appliance resp. customer scheduling can be implemented to reduce peak loads, costs or carbon dioxide/greenhouse gases emissions, to ensure power systems stability and reliability and to prefer renewable energy sources.

Main objective of the ESF founded research project SyNergIt is to develop control mechanisms for smart grids with focus on the ability to respond to different energy generation and consumption scenarios of locally distributed data centres (Virtual Network Embedding). This approach uses real example data of wind power plants and data centres to forecast generation and consumption as a basis for direct smart grid control via energy pricing. The functionality of the approach and some basic results will be presented.

#### 2 - Virtual Machine Migration and Resource Reallocation: A Multi-Step Approach

*Nguyen Tuan Khai, Andreas Baumgartner, Thomas Bauschert*

Virtual Machine Migration (VMM) is a process of relocating a virtual machine (VM) from one host to another. VMM is desirable e.g. in case of server maintenance and significant changes in resource demands or if the operational costs of the data centers considerably change (e.g. due to changes in the local energy prices). VMM also requires the rerouting of inter-VM traffic flows. If the migration process must be conducted within a fixed time limit (migration deadline), certain constraints are imposed on the data center network. For instance, before the process is triggered, a minimum capacity needs to be available in

the network to perform the migration within the deadline. However, for one-step VMM, due to the limited network resources, solely relying on the residual capacity is not adequate to ensure a feasible migration solution. In this work, we consider a multi-step migration approach and take into account the so-called "soft bottlenecks", which refer to capacity bottlenecks caused by the preoccupation of capacity due to existing virtual networks and other migration processes. By taking advantage of the possibilities for releasing and relocating these soft bottlenecks, the hosting capability of the data center infrastructure can be fully explored, and VMM can be made feasible while guaranteeing the fulfillment of the migration deadlines. Our new migration model is based on a mixed integer program (MIP), whose objective is to minimize the required migration steps. It is applied on a realistic network topology instance taken from SNDlib. The results show that situations might occur in which, contrary to our multi-step approach, single-step migration is not feasible.

### 3 - Synergetic Optimization of Communication and Power Networks

*Anja Hähle, Christoph Helmberg*

The increased inclusion of renewable energies in the electricity system leads to great challenges. One of these is the balancing of load and generation in the power grid. At the same time, the energy demand of the ICT sector is constantly on the rise. Data center demand response is becoming a relevant factor in load balancing. We study possibilities arising from the fact that their loads can be shifted between various geographical locations as well as in time in order to improve the stability of power-grid-models under regional energy differences.

We present an approach of using coupled time-expanded networks to model the shifting of virtual machines (VMs) embedded into the physical infrastructure between data centers as well as to control the on-off status of servers and power units. The arising discrete multi-commodity flow problems are then coupled to the Optimal-Power-Flow problem (OPF) with the aim to optimize the operation of the power grid. We also discuss some solution strategies and first experimental results for the above problems.

## ■ TD-07

*Thursday, 14:45-16:15 - WGS|106*

### Computational Mixed-Integer Programming 3

Stream: Discrete and Integer Optimization

*Parallel session*

Chair: *Ambros Gleixner*

#### 1 - Recent developments in the CPLEX solver

*Roland Wunderling*

We will discuss the most recent improvements in CPLEX 12.7.1

#### 2 - Current Status and Future Developments of the SAS MILP Solver

*Philipp Christophel*

We give an overview of the current status of the SAS mixed integer linear programming (MILP) solver and outline future development efforts.

#### 3 - Recent Advances in Gurobi 7.0

*Michael Winkler, Tobias Achterberg*

We will give an overview on new features of the current Gurobi release including multi-objective support, the new solution pool capabilities, and the improved new modeling features. Additionally we will talk about performance improvements and our new Instant Cloud.

#### 4 - Satalia's Solving Genie: The SolveEngine

*Vito Tumas, Yuri Moskvic*

The SolveEngine provides optimisation-as-a-service. We aggregate, maintain and license a wide range of best-in-class solvers. Users simply submit a problem (SAT, MIP, CP, QP and soon, MINLP) to a cloud server, and the SolveEngine selects the best-suited solver for that particular problem. The SolveEngine is algorithm agnostic, and is constantly updated with algorithms from both academic and commercial communities, ensuring the system is consistently cutting edge. User's pay only for the SolveTime they use, and algorithm providers generate revenue from royalties.

In this talk, we will outline which solvers, algorithms, modelling languages and solve systems have already been integrated into the SolveEngine. We will describe how everyday users can access the SolveEngine, and for more advanced users, explain how existing systems can access the SolveEngine through our API's. We will provide details of our beta version, and explain how machine learning will be used to extract features from your problem in order to determine which solver to send it to and continuously improve the performance of the SolveEngine. We will conclude with a description of how algorithm creators can seamlessly integrate their own algorithms into the SolveEngine and start generating revenue to fund future development, as well as gain and insights into the performance of their creations to support further development and advancement.

## ■ TD-08

Thursday, 14:45-16:15 - WGS|107

### Urban Transport

Stream: Traffic, Mobility and Passenger Transportation  
Parallel session

Chair: Jörn Schönberger

#### 1 - An Integrated Optimization-Simulation Approach for Sustainable Urban Transport

Marcus Brandenburg, Werner Jammernegg, Matthias Kannegiesser, Manfred Paier, Tina Wakolbinger

Urban transport is exposed to massive sustainability challenges, e.g. emissions and air pollution, costs and congestion time delays, negative social health impact, consumed space, population growth and further urbanization. A fundamental transformation of urban transport towards sustainability over the next decades is required. New power-train technologies, mobility models and changed user behavior provide opportunities for the transformation. The strategic planning problem is substantially complex and dynamic. Thus, city decision makers and other stakeholders need advanced decision support tools to understand, plan and manage the transformation. We present the cornerstones of a new research project that aims at developing a decision support approach to answer, if, when and how a transition towards sustainable urban transport can be reached and which alternative transition scenarios exist. The real-life planning problem needs to consider active decision making and optimization (e.g. infrastructure investment decisions), dynamics of influencing external scenario drivers (e.g. technology cost developments or demographics) as well as the interplay of stakeholders (e.g. in negotiations on regulation options for city logistics). We present the scope, requirements and research approach as well as initial hypothesis and interim results. The model architecture foresees a new integrated optimization-simulation approach that combines multi-objective time-to-sustainability optimization for urban transport with system dynamics and multi-agent simulation to model external parameters. Heuristics is applied for model integration and handling of sub-problems. We plan to numerically analyze three real life cities (Vienna, Berlin and Kassel) with the integrated approach.

#### 2 - Traffic Speed Prediction with Neural Networks

Umut Çakmak, Mehmet Serkan Apaydin, Bülent Çatay

Traffic speed and flow prediction has started attracting more attention in contemporary transportation research with the growing interest in creating Smart Cities. Neural networks have been utilized in many studies to tackle this problem; yet, the proposed methods have focused on the short-term traffic prediction while longer forecast horizons are needed for more reliable mobility and route planning. This study aims to fill this gap by addressing the mid-term forecasting as well as the short-term. Our approach employs a feedforward backpropagation neural network that combines different time series forecasting techniques such as naïve, moving average and exponential smoothing where the predicted speed values are fed into the network as inputs. We train our neural networks and select the hyper-parameters of the network structures to minimize the mean absolute error, which yields the best setup for further forecast input. In our experimental study, we considered two routes from the city of Istanbul in Turkey. Both routes have a length of around 20 kilometers and include 63 and 324 road segments. The floating vehicle data is provided by Başarsoft Company and consists of speeds observed every minute over a 5-month horizon. Our computational tests showed that the most accurate predictions are

achieved when a combination of forecasting methods and the information from neighboring segments are supplied into the feedforward backpropagation neural network.

#### 3 - Ticket Portfolio Planning for Zone-based Public Transport Tariffs -Time-Oriented Product Discrimination

Jörn Schönberger

Public transport providers have to define transport services to fulfill a diversified set of mobility demand. Passengers buy a mobility product in order to be entitled to use a public transport service. The correct purchase of a public transport product is typically represented by a ticket. Challenges of the planning of the transport services are well-investigated and a bunch of operations research models are proposed to support the corresponding planning tasks. In contrast, relatively few research work is dedicated to plan and support the product definition. In this contribution, we report about models and their evaluation for the planning of offered products, i.e. the specification of the portfolio of offered public transport tickets. Special regard is paid to the influence of time-related aspects like the time when a ride takes place. Furthermore, we discuss the consideration of time-related discounts like period-tickets.

## ■ TD-09

Thursday, 14:45-16:15 - WGS|108

### Robust Combinatorial Optimization (i)

Stream: Discrete and Integer Optimization

Parallel session

Chair: Jannik Matuschke

#### 1 - New MIP Formulations for the Steiner Forest Problem

Daniel Schmidt, Bernd Zey, Francois Margot

We compare linear programming bounds obtained from various Steiner Forest integer programming formulations in an experimental study and propose two new directed formulations for the problem. It turns out that the new formulations provide strong linear programming bounds.

#### 2 - Robust Randomized Matchings

Jannik Matuschke, Martin Skutella, Jose Soto

The following zero-sum game is played on a weighted graph: Alice selects a matching  $M$  and Bob selects a number  $k$ . Then, Alice receives a payoff equal to the ratio of the weight of the  $k$  heaviest edges of  $M$  to the maximum weight of a matching of size at most  $k$  in the graph. If  $M$  guarantees a payoff of at least  $L$  then it is called  $L$ -robust. In 2002, Hassin and Rubinfeld gave an algorithm that returns a  $\sqrt{1/2}$ -robust matching, which is best possible.

In this talk, we will see that Alice can improve on the guarantee of  $\sqrt{1/2}$  when allowing her to play a randomized strategy. We devise a simple algorithm that returns a  $1/\ln(4)$ -robust randomized matching, based on the following observation: If all edge weights are integer powers of 2, then a lexicographically optimum matching is 1-robust. We prove this property not only for matchings but for a very general class of independence systems that includes matroid intersection,  $b$ -matchings, and strong 2-exchange systems. We also show that our robustness results for randomized matchings translate to an asymptotic robustness guarantee for deterministic matchings: When restricting Bob's choice to cardinalities larger than a given constant, then Alice can find a single deterministic matching with approximately the same guaranteed payoff as in the randomized setting.

#### 3 - Mixed Integer Reformulations of Robust $b$ -Matching Problems

Frauke Liers, Lena Maria Hupp, Manu Kopolke, Alexander Martin, Robert Weismantel

In this talk, we consider robust two-stage bipartite  $b$ -matching problems with one or several knapsack constraints. Following the approach of Bader, Hildebrand, Weismantel, and Zenkussen (2016), we show how to reformulate the integer programming (IP) formulations of the two-stage bipartite  $b$ -matching problems as MIPs that only use few integer variables. To preserve integrality, an appropriate affine TU decomposition of the constraint matrix needs to be found. In the case of the two-stage bipartite  $b$ -matching problem with only one knapsack constraint, we present an affine TU decomposition and show that in a

specific MIP reformulation the number of integral variables only depends on the number of nodes in one shore of the graph. For the two-stage bipartite b-matching problem with several knapsack constraints, an appropriate affine TU decomposition cannot be derived in a straight forward way. However, we present a similar decomposition of the constraint matrix and prove that this decomposition preserves integrality and thus allows a MIP reformulation with less integer variables. Applications of such robust two-stage bipartite b-matching problems are in robust runway scheduling in air traffic management. Each aircraft is assigned a time slot at the first stage before the uncertainty reveals. If an disturbed scenario occurs the plan might become infeasible and the aircraft need to be replanned in the second stage. The restriction of the replanning action may be modeled by one or several special knapsack constraints. Experimentally, we show that when compared to solving the standard IP formulation, root bounds as well as the CPU times are improved significantly. Moreover, several instances can only be solved using MIP reformulations.

## ■ TD-10

Thursday, 14:45-16:15 - WGS|108a

### Online-Algorithms

Stream: Discrete and Integer Optimization  
*Parallel session*

Chair: *R. Hildenbrandt*

#### 1 - On-line Algorithms for Controlling Distribution Conveyors and Multi-line Palletizers

*Jochen Rethmann, Frank Gurski, Egon Wanke*

We consider the distribution problem for multi-line palletizing systems which arises in delivery industry, where bins have to be stacked-up from conveyor belts onto pallets with respect to customer orders. The bins reach the palletizer on the main conveyor of an order-picking system. A distribution conveyor pushes the bins out to several buffer conveyors. Robotic arms are placed at the end of these buffer conveyors where each arm picks-up the first bin of one of the buffer conveyors and moves it onto a pallet located at stack-up places. In this paper we present an online algorithm to distribute bins to the buffer conveyors, and we analyse how many stack-up places are required to palletize the bins with respect to this distribution.

#### 2 - Optimizing Address Mappings of DRAMs with Fixed Access Patterns

*Marco Natale, Sven Krumke*

Dynamic Random Access Memories (DRAMs) are fundamental components of today's computers, which allow (volatile) data storage at a very high density. However, due to architectural limitations only a certain amount of data can be cached and made available for fast access. Accessing non-cached data comes at high costs in both time and energy. Therefore, the efficiency of a DRAM is highly dependent on how the data is stored internally. In general purpose systems like personal computers it is not fully determined in advance how the data is accessed and decisions can be made only online. Nonetheless, numerous systems, such as embedded systems, possess regular or fixed access patterns. This global view allows storage of the data such that the time and energy consumption is minimized. In our model a DRAM consists of several banks each of which is subdivided into rows. Per bank at most one row can be cached and addresses in such a row can be accessed for free. Accessing a non-cached address, however, comes at one unit cost. The goal is to remap the addresses such that the cost of a fixed access pattern is minimized. In general this problem is NP-hard to approximate. However, we show that locality properties of the input sequence can be exploited to obtain polynomial time algorithms for a wide class of sequences.

#### 3 - The k-server problem with parallel requests and the corresponding generalized paging problem

*R. Hildenbrandt*

In this talk we want to discuss several algorithms for solving the k-server problems with parallel requests where several servers can also be located on one point. We are given initial locations of k servers in a finite metric space. Requests for service at several points come in over time. Immediately after the t-th request is received, a sufficient number of servers must be moved from their current locations to the

request points in order to fulfil the request. The choice of which servers are moved, must be made based only on the current servers configuration and on the requests seen so far. Moving servers cost the distances the servers are moved, and the goal is to minimize the total cost. The (usual) k-server problem, where at most one server must be moved in servicing the request in each step, was introduced by Manasse, McGeoch and Sleator in 1988. The investigation of the generalized k-server problem with parallel requests was initiated by an operations research problem which consists of optimal conversions of machines or moulds. Based on well-known algorithms (as the Harmonic or the work function algorithm), we will develop new algorithms and show their qualities for solving the generalized problem. We will also do that for the specific case where all distances are equal (generalized paging problem).

## ■ TD-11

Thursday, 14:45-16:15 - WGS|005

### Vehicle Routing - Heuristics II

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: *Sandra Huber*

#### 1 - A solution approach for the k-dissimilar vehicle routing problem with practical requirements

*Sandra Zajac*

In the Capacitated Vehicle Routing Problem (CVRP), customers have to be served exactly once, all vehicles of an unlimited fleet begin and end at the depot, and the capacity limit of each vehicle is respected. We consider three additional practical requirements to this academic problem. First, the classical problem description does not explicitly take the solution shape into account. However, in practice it is often required that the routes are visually attractive as those are more likely to be accepted by the decision makers. The visual attractiveness of a solution can be measured among others by its compactness. Second, for each used vehicle fixed costs arise. Since compact routes can be easily achieved by deploying many vehicles, a trade-off emerges between maximizing the compactness and minimizing the number of vehicles. Finally, it is common practice to present a set of k dissimilar solution alternatives to the management before a decision is taken. Since short routings tend to be similar to each other, an objective conflict arises between minimizing the distance of the longest routing and maximizing the minimum dissimilarity between a pair of routings. In this talk, the described k-dissimilar vehicle routing problem with practical requirements is studied. A variable neighborhood search is presented which obtains the approximated Pareto set. A computational study on selected instances of the CVRP is conducted. For an easier comparison in future, the best known solutions of the instances are mandatorily included in the set of the k solution alternatives. Two specialized neighborhoods are introduced which increase the compactness of the routes and ensure that the number of available vehicles is not exceeded. First promising results will be reported at the conference.

#### 2 - Just-in-Time Route Optimization for Urban Delivery Processes

*Sebastian-Adam Gebski, Patrick Czerwinski, Marc-Oliver Sonneberg, Max Leyerer, Michael H. Breitner*

As city logistic activities represent a driver for innovative and disruptive business models, services like 'Uber' or 'Lyft' are examples for successful on-demand transportation. Instead of passengers, the transportation of goods could also be offered as an on-demand service. We investigate a food delivery service that offers fresh dishes, which are transported by multiple pre-packed scooters or cargo bicycles. This business model is characterized through low delivery costs for suppliers and very short delivery times for customers. As food orders can be received at any time, just-in-time route optimization is required. To satisfy these orders, drivers are assigned to multiple customers and each driver's route can be changed with a new order. If a driver is out of stock, the driver finishes his trip. We formulated an optimization model that is based on a classical vehicle routing problem (VRP) extended by multiple depots and open routes. In this case, the drivers itself are defined as depots with a limited storage capacity for dishes to fulfill customer needs. Based on the food orders, the model uses live tracking information for the input parameters and has cost-minimized



routes for each driver to support the operational service of a food delivery service. However, the optimization model could be used for other business models. For instance, open routes and multiple depots occur in vehicle rental and logistics sector.

### 3 - A matheuristic based on Variable Neighborhood Search for the Swap-Body Vehicle Routing Problem

*Sandra Huber, Jean-François Cordeau, Martin Josef Geiger*

This talk presents a solution approach for the Swap-Body Vehicle Routing Problem (SB-VRP), which was announced by the EURO working group on Vehicle Routing and Logistics Optimization (VeRoLog) in collaboration with the German company PTV Group. We employ a matheuristic consisting of a Variable Neighborhood Search and a set-partitioning formulation. In a first phase, feasible alternatives are computed by means of four standard operators, such as e.g. a 2-OPT and an inter-move that can reposition a customer in another tour. Throughout the search, feasible, distinct routes are kept in memory. After that, routes in the pool are selected, which minimize the total routing cost. Our solution approach is tested for several benchmark instances, which are available on the VRP-repository. Computational results show that several instances can be improved by the matheuristic. However, for some instances the combination does not give an advantage. Currently, we are working on additional operators in order to enhance the pool of routes. One of the ideas is to merge two truck tours in one train tour. Several swap locations for the train tour are tested, which are close to both truck tours.

## ■ TD-13

*Thursday, 14:45-16:15 - RVH|I*

### Smart Services and Internet of Things II

Stream: Business Analytics, Artificial Intelligence and Forecasting

*Parallel session*

Chair: *Maria Maleshkova*

#### 1 - Exploring the Formation of Blockchain-driven Business Networks

*Stefan Seebacher*

It is hypothesized that blockchain technology has the potential to affect a vast variety of different industries and services, thereby, disrupting existing business models and market structures. Until now, current research has mostly focused on the assessment of the technical characteristics as well as on the potential impacts of blockchain technology. However, other aspects remain still unexplored. For instance, it is not investigated how business networks form in such a setting and how smart contracts and the blockchain's underlying chain code can be efficiently composed to facilitate the realization of blockchain projects.

The goal of the research at hand is to close this gap, bridging technical and economic aspects, therefore, trying to answer the following research question: "What kind of patterns can be identified, assessing blockchain-driven business networks, to facilitate their modularization and chain code?"

Existing business networks that apply blockchain technology serve as the main data source for this research inquiry. In particular, the data is collected by assessing existing Hyperledger projects. In this regard, a semantic model is developed, which describes all relevant aspects of a blockchain-driven business network. For the pattern analysis, open coding and clustering algorithms (e.g. PCA, k-medoids) are applied to potentially identify different levels of patterns. Based on these patterns, network components, such as smart contracts, are modularized with respect to the corresponding use case and domain. Thereby, the research inquiry extends the body of knowledge concerning blockchain, on a business network level, and gives guidance to practitioners who are aiming to integrate the technology into their current business networks.

#### 2 - Estimating Downtime Costs using Simulation

*Clemens Wolff, Michael Vössing*

Recent trends in industrial maintenance have indicated a shift from traditional transactional maintenance towards long-term maintenance contracts, in which the service provider guarantees a certain pre-defined equipment availability level. Due to this development, industrial manufacturers need to be able to determine suitable long-term

equipment availability levels for contracting. One approach of doing so is by using Service Level Engineering (SLE). SLE identifies a cost-optimal equipment availability by balancing the costs of additional equipment uptime against the costs of missing uptime - in other words, downtime costs.

When calculating the cost of downtime, opportunity costs, such as lost production output, must be considered. While for simple production systems, production loss quantities can be calculated analytically through Graph Theory, more complex systems require new sophisticated models. In this work, we propose an approach for estimating production output losses due to individual asset downtime through simulation. The production output shortages can then be monetarized and accounted for when calculating downtime costs.

By including manufacturing dependencies between multiple production assets as well as production unit flexibility, we aim to estimate production system-wide costs of downtime that are associated to individual assets downtime within the production system.

There are three promising areas of application for these insights: First, knowledge of downtime costs of individual assets can be used to prioritize maintenance activities. Second, we aim to look at maintenance scheduling from a system perspective, thus also taking downtime costs of customers into account. Third, they can be used to apply SLE.

#### 3 - Data-driven Decision Support for Field Service Planning

*Michael Vössing, Clemens Wolff*

Efficient delivery of maintenance, repair and overhaul services has become a priority for many manufacturing companies. In particular, field service planning — the process of allocating field service employees to spatially distributed service requests, remains a challenge largely managed by dispatchers with little technical support. To increase planning efficiency many companies are evaluating decision support systems (DSS) and automation. The operations research community has developed numerous exact and approximate solution methods for similar problems, but in some cases the applicability of these solutions to real-world problems is limited. Previous research has identified that the complex, deterministic, and dynamic nature of the field service planning process makes it a unique problem.

This work focuses on two aspects: (A) Industrial field service planning requires multiple preparation steps — e.g. problem identification, task prioritization, request to employee matching, and planning parameters estimation (e.g. future demand, characteristics of requests), before requests can be scheduled. As companies rely on dispatchers, their decision processes and accumulated knowledge are tacit and, therefore, currently cannot be leveraged for DSS and automation. (B) Dispatchers often experience cognitive overload as multiple information sources must be evaluated simultaneously under time pressure. Simple DSSs, which automatically estimate planning parameters that are difficult to estimate manually, can already enable dispatchers to focus their attention where it is needed most.

Exemplary, a data-driven DSS for the robust prediction of planning parameters, based on historic service information and (often incomplete) real-time data, is presented and evaluated.

## ■ TD-14

*Thursday, 14:45-16:15 - RVH|II*

### Human Decision Making in Revenue Management

Stream: Pricing and Revenue Management

*Parallel session*

Chair: *Catherine Cleophas*

#### 1 - Prediction and Learning with Expert Advice in Airline Revenue Management

*Stefan Franz, Esther Mohr, Christiane Barz*

We introduce a new approach for determining booking limits for the static single-leg revenue management problem in absence of a probabilistic model for the demand. Aiming at a minimization of regret, our approach is based on prediction with expert advice. We evaluate our approach in a simulation.

## 2 - Considering Human Decision Making in Revenue Management Given Diverse Decision Tasks

*Claudia Schuetze, Catherine Cleophas*

Revenue management has become a crucial success factor for many service industries such as ho-tels, car rentals, and airlines. It embodies the idea of maximizing revenue by optimizing the set of offered products, given limited capacity and predicted demand. To complement automated revenue management systems, firms employ revenue analysts. In consequence, the interaction between system and analysts plays a decisive role for revenue management in practice. Therefore, we investigate human decision making in a revenue management setting to draw conclusions for the design of decision support systems.

On the one hand, analysts can be tasked to balance multiple objectives, such as short-term revenue managerial KPIs, such as market share or capacity utilization. Currently, automated revenue management systems rarely consider multiple criteria, but exclusively focus on maximizing revenue. We analyse how well analysts are able to balance those multiple objectives given different framings of the task in a controlled experiment.

On the other hand, analysts influence system parameters rather than deciding whether to accepting individual customer requests or how many seats to assign to a booking class. While existing research mainly focuses on those decision tasks, we test the effect when the analysts' influence is framed in a more indirect way, given aspects of anchoring and algorithm trust.

## 3 - Balancing Revenue and Load in Capacity-Based Revenue Management

*Felix Geyer, Christina Büsing, Catherine Cleophas*

In revenue management, maximizing revenue and secondary business objectives play a significant role for the long-term success. An important objective is the number of sold units, also expressed as load, as it is related to strategical targets and stock valuations. For instance, after launching a new service, the firm may want to maximize the number of early adopters and stimulate the demand in the short-term to increase long-term revenue potential. In practice, automated systems are used to maximize revenue by optimizing inventory controls for capacity-based revenue management. But the revenue-maximal solution may not align with the secondary objective of maximizing load. Hence, analysts manually overrule the automated optimization to improve the secondary objective. Such manual interventions are unlikely to achieve an optimal balance of objectives. Thus, we suggest to include the secondary objective in the optimization model to calculate a Pareto-curve as decision support to the analysts. We formulate a bi-objective optimization problem based on the classic independent demand revenue management problem and present a dynamic programming approach to calculate a complete solution set of optimal trade-offs. Furthermore, we provide a heuristic to approximate the optimal solution set and show its quality in a numerical study.

This work presents a comprehensive System Dynamics model aimed to qualitatively understand how each major element integrated into the air transport system defines the complex dynamics involved in the development of this industry. Unlike other System Dynamics efforts focusing on the aviation industry, this model represents the first attempt to capture the overall dynamics of multiple stakeholders, namely passengers, airports, airlines and aircraft manufacturers. Furthermore, this constitutes another step towards modeling the air transport system on a global scale, while simultaneously allowing its regional disaggregation.

While most System Dynamics publications provide detailed explanations on the logic underneath the models and the insights obtained from them, this particular work is approached from the methodological standpoint. This perspective considers the aspects required for building meaningful models, based not only on expert knowledge and modeler's intuition but also aided by data science techniques to extract information from exhaustive data on the analyzed system.

## 2 - An agent-based simulation using conjoint data: the case of electric vehicles in Germany

*Markus Günther, Marvin Klein, Lars Lüpke*

Agent-based simulation has become increasingly popular in innovation and technology diffusion research as it enriches traditional approaches (like those based on differential equations or system dynamics approaches) by explicitly modeling the diffusion process at a micro level. This allows especially for considering the heterogeneity of consumers who differ in their preferences, are geographically distributed across regions, are connected to each other in various ways within their social system, and act as well as react based on their limited available information. Otherwise, agent-based approaches are sometimes criticized as 'toy models', especially if they lack of empirical foundation and therefore do not adequately represent actual behavior in real markets. Even if empirical grounded, parameters are - more often than not - derived from (aggregated) sociodemographic datasets and individual choice-behavior is therefore not adequately captured. Thus, profound parametrization as well as validation of agent-based models is often neglected, especially in the case of electric vehicles. In order to overcome these limitations, we present an agent-based simulation approach that builds on empirical data derived primarily from a choice-based-conjoint-analysis. Furthermore, a cross-model validation is performed. Our application case focusses on the generation Ys' (future) adoption behavior of electric, plug-in electric and conventional vehicles in Germany. The model at hand allows for analyzing various impacts like technological progress (e.g. in range, charging time, consumption costs, or station density), subsidies, marketing, and previously unstudied effects arising from the possibility of home charging.

## 3 - Simulation of a Service Station in a Public Transportation System

*Malte Thiede, Lars Stegemann, Daniel Furstenuau, Martin Gersch, Hannes Rothe*

The simulation of heuristic problems of timetable and rotation planning is a well-established procedure in the local public transport for years. However, agent-based approaches like MATSim have additional potentials, which extend beyond the usual application. This contribution illustrates one of these potentials using the example of the introduction of a service station in the service system of a public transport provider. In a five-step procedure, this service is analyzed and modeled for the simulation. The results of the simulation provide further direction for the specific requirements of these service stations. The case study shows, on the one hand, the usefulness of simulation in a complex service system. Thus, both service station-specific parameters, such as location combinations, capacity or service life, as well as market-economy data, such as utilization, can be calculated. On the other hand, the case also shows the limitations, such as the high computational cost.

## ■ TD-15

Thursday, 14:45-16:15 - RVH|III

### Modelling and Simulation Applied to Transportation Systems

Stream: Simulation and Statistical Modelling  
*Parallel session*

Chair: *Malte Thiede*

#### 1 - The European Air Transport System: Data Analysis for System Dynamics Modeling

*Gonzalo Barbeito, Marcia Urban, Ulrike Kluge, Maximilian Moll, Kay Plötner, Martin Zsifkovits, Stefan Wolfgang Pickl, Mirko Hornung*

Due to an ever-increasing complexity in aviation related operations, modeling and simulation became widely used tools for analyzing the underlying systems and their associated behavior. System Dynamics is a well-known technique capable of handling such complexity, through the development and simulation of models involving medium to high levels of aggregation. Such aggregation allows to qualitatively assess the system as a whole, by studying the interrelations of different internal operations and exogenous effects, and their contribution to the system's general behavior.

## ■ TD-16

Thursday, 14:45-16:15 - RBM|1102

### Assembly Line Planning

Stream: Production and Operations Management  
*Parallel session*

Chair: *Tobias Kreiter*

### 1 - Flexible layouts for the mixed-model assembly of heterogeneous vehicles

Andreas Hottenrott, Martin Grunow

The increasing vehicle variety and heterogeneity is pushing the widespread mixed-model assembly line to its limit. In alternative flexible layouts, the assembly stations are no longer arranged in a serial manner and no longer linked by a paced conveyor belt but automated guided vehicles. Such flexible assembly layouts can improve makespan, station utilization and disruption risk resilience in a low volume, high variety product environment. However, these advantages come at the expense of an increase in production and transportation complexity. Our objective is therefore to analyze under which circumstances flexible assembly layouts are in fact superior to mixed-model assembly lines. We provide a mixed-integer linear model formulation and develop a decomposition-based solution procedure to generate flexible layouts for the final assembly of heterogeneous vehicles in static environments. Our solution procedure can be employed as an exact or heuristic approach. We compare the performance of flexible layouts against mixed-model assembly lines.

### 2 - Using Extreme Value Theory to Model Assembly Line Balancing Problem with Stochastic Task Times

F. Tevhide Altekin

In this study, we deal with the stochastic assembly line balancing problem. We assume task times are normally distributed with known means and standard deviations. Although the work contents assigned to the stations are also normally distributed, the maximum of these work contents is not normally distributed. Extreme value theory is used to represent similar extreme order statistics of normally distributed samples in various fields such as energy, finance, and engineering. After providing an overview of extreme value theory approaches, we exploit three approximations to model the distribution of the maximum work content by using Gamma, Normal and Gumbel distributions. So as to estimate the parameters of these distributions, we also compare and contrast different approaches to estimate the expected value and the standard deviation of the maximum work content. A comparison of the approximations is provided using examples from the assembly line balancing literature.

### 3 - Production Sequencing of Multi-level Mixed-Model Assembly Lines

Tobias Kreiter, Ulrich Pferschy

Increasing product variations and highly individual customer requests motivate manufactures to shift from classical large batch size production environments to mixed-model assembly lines extending towards the separate consideration of each individual product. However, an assembly line should still be run with constant speed and cycle time. Clearly, the consecutive production of different models will cause a highly unbalanced temporal distribution of workload. This can be avoided by moving some assembly steps to pre-levels thus smoothing out the utilization of the main line. In the resulting multi-level assembly line the sequencing decision on the main line has to take the balancing of workload for all pre-levels indirectly into account to assure that the modules or parts delivered from the pre-levels do not cause congestion but are adjusted to the sequence of the main line. One planning strategy aims at mixing the models on the main line to avoid blocks of identical units. We present a Mixed-Integer Programming model (MIP) for this approach and enrich it with a number of relevant practical extension. On the other hand, we illustrate how this strategy and its extensions could be (to some extend) realized in an advanced planning system linked to an Enterprise Resource Planning (ERP) system, namely SAP APO. Then, we also give a MIP model for the actual objective of explicitly balancing pre-level workloads. Finally, we present computational experiments for a real-world production planning problem of a company producing engines and gearboxes. We compare the possibilities and limitations as well as the computational performance of MIP models and the realizations in SAP APO.

### 1 - Appointment Scheduling Strategies for Medical Group Practices

Julia Block, Lisa Koppka, Matthias Schacht, Brigitte Werners

In a medical group practice consisting of several primary care physicians (PCPs) patient occurrence and demand for medical treatment fluctuates depending on the PCP and the weekday. Walk-in patients (walk-ins) seek for a same-day treatment and join the practice especially at the beginning of the week. In addition to walk-ins there are patients who book their appointments in advance (preschedules). For preschedules who prefer a given appointment with their personal PCP on a specific time and day, appointment slots are provided. By offering appointment slots on days with a small expected amount of walk-ins, demand can be channeled to match the capacity leading to shorter waiting times. Requests for appointment slots may differ between the PCPs. In order to achieve a more balanced utilization of PCPs, less frequented PCPs may treat more walk-ins than the ones with high demand for appointments. Thus, demand for medical treatment can be shifted in two different ways: firstly, between weekdays and secondly, between the PCPs. We extend current interday appointment scheduling models by integrating multiple PCPs. We present a concept for an extended MILP whose optimal solutions on the tactical level are evaluated in an extensive simulation study on the operational level where uncertain patient occurrence and preferences, treatment times and urgent requests are considered.

### 2 - A Genetic Algorithm for the Vehicle Routing Problem with time window and temporal synchronization constraints

Stephan Hocke, Christina Hermann, Mathias Kasper

This paper presents a genetic algorithm for the Vehicle Routing and Scheduling Problem with time windows and temporal synchronization constraints. That means that as opposed to the usual procedure, in addition to the usual task covering, some vertexes must be served by more than one vehicle at the same time. The mathematical model relates on a work of Mankowska et al. (2014) who describe a daily planning of health care services carried out at a patient's home by staff members of a home care company. The chromosome coding used here is based on their proposed solution representation. The genetic algorithm was able to solve the instances of Mankowska et al. (2014) up to 20 patients near to optimality. Even in greater instances with 100 patients the solution quality of the genetic algorithm outperforms the local search presented by Mankowska et al. (2014), however with losses in runtime. In order to get more comparable results, both solution approaches are evaluated at the well-known benchmark instances of Bredström and Rönnqvist (2008). This includes the presentation of a simple repair algorithm during the chromosome crossover based on an insertion heuristic in order to achieve the hard time window constraints of the benchmarks.

#### References

Bredström D., and Rönnqvist M. (2008): Combined vehicle routing and scheduling with temporal precedence and synchronization constraints, In: *European Journal of Operations Research*, Vol. 191, Issue 1, pp 19-29. Mankowska D. S., Meisel F., and Bierwirth C. (2014): The home health care routing and scheduling problem with interdependent services, In: *Health Care Management Science*, Vol. 17, Issue 1, pp 15-30.

### 3 - Planning of out-of-hours service for pharmacies

Timo Gersing, Christina Büsing, Arie Koster

The supply of pharmaceuticals is one important factor in a functioning health care system. In the German health care system, every citizen must by law find an open pharmacy at any day and night time within a certain distance. To that end, every pharmacy has to take over some out-of-hours shifts over the course of a year. These shifts are highly unattractive since they are unprofitable and stressful for the pharmacist who has to work for 24 consecutive hours. The out-of-hours service is typically organized locally within small districts as cities or municipalities. In this talk, we present a centralized planning to reduce the load of shifts and to distribute them evenly among the pharmacies. Such an out-of-hours plan has to meet several constraints: the coverage of the whole population; rest periods between two shifts; minimum distance between open pharmacies. As a combination of a set cover, scheduling and independent set problem, this problem is NP-hard. To solve the problem, we present a matheuristic based on a rolling horizon approach. Finally, we analyze the obtained out-of-hours plan for the area Nordrhein in 2017 and compare it with the current out-of-hours plan.

## ■ TD-17

Thursday, 14:45-16:15 - RBM|2204

### Planning Health Care Services

Stream: Health Care Management  
Parallel session

Chair: Teresa Melo

## ■ TD-18

Thursday, 14:45-16:15 - RBM|2215

### Resource Planning and Production Planning

Stream: Project Management and Scheduling  
*Parallel session*

Chair: Markus Seizinger

#### 1 - Dynamic resource scheduling problem for audit planning

*Ethem Canakoglu, Ibrahim Muter, Onur Adanur*

Resource scheduling has been one of the most prominent problems in the operations research literature due to its technical challenges and prevalence in real-life. These problems include a set of tasks, resources to perform these tasks under some constraints (resource capacity, time limitations, etc.). In this paper, we focus on an extension of the parallel machine scheduling problem with additional resources. This problem also arises in audit scheduling in which the local branches of a financial firm are to be audited by a team of auditors with different experience levels. The quantification of the auditor experience and the branch experience requirement enables us to model this problem as an extension of the aforementioned scheduling problem with some extra constraints and objectives related to the auditing process. Due to the dynamic structure of team building problem, it can be classified as a dynamic resource constrained parallel machine scheduling problem with unspecified job-machine assignment. We build mathematical models for these problems and propose heuristic algorithms to find upper bounds for the problem. We analyze the effectiveness of algorithms through computational experiments on the generated instances.

#### 2 - Strategic planning of new product introductions in the automotive industry

*Christopher Valentin Bersch, Renzo Akkerman, Rainer Kolisch*

The timing of the introduction of new vehicles is an important strategic concern in the automotive industry and a complex decision problem for a variety of reasons. First, due to the use of platform-based planning, shared modules create many interactions between the individual products. Secondly, new product development projects rely on various shared resources. Furthermore, many potentially conflicting objectives must be considered in such a long-term planning problem. We are addressing this problem by presenting a mixed-integer linear programming model for the timing of the introduction of new vehicles, which is building on modelling concepts of multi-project scheduling. Using data from a major German automotive company, we are presenting the computational performance of our model, when solved with state-of-the-art solvers, as well as managerial insights.

#### 3 - The two dimensional bin packing problem with layer constraints

*Markus Seizinger, Andreas Fügener, Jens Brunner, Alessio Trivella*

We propose a new variant of Bin Packing Problem, where rectangular items of different types need to be placed on a two-dimensional surface. This new problem type is denoted as two-dimensional Bin Packing with layer constraints. Each bin may consist of different two-dimensional layers, and items of different types may not overlap on different layers of the same bin. By different parameter settings, our model may be reduced to either a two- or three-dimensional Bin Packing Problem. We illustrate real applications, such as paint shops or compartment trucks. We further propose lower bounds, efficient heuristics, and a column-generation scheme that manages to find near-optimal solutions in realistic time. An extreme-point heuristic is applied to approximate the packing subproblem.

## ■ TD-19

Thursday, 14:45-16:15 - RBM|3302

### Production Planning & Control

Stream: Production and Operations Management  
*Parallel session*

Chair: Justus Arne Schwarz

#### 1 - Optimization of processing rates in stochastic operations systems

*Raik Stolletz, Jannik Vogel*

A key challenge in production and service systems is to adapt the resource capacity to a time-dependent and uncertain demand. The aim of this paper is to gain insights on how the information on demand changes influences the optimal control of the processing rate of a stochastic multi-server system.

We model that system as a single-stage  $M(t)/M(t)/c$ -queue. A non-homogeneous Poisson process with instantaneous arrival rate  $\lambda(t)$  creates arrivals to this system. The decision is to choose optimal processing rates within a given range. The objective function considers holding cost and service cost proportional to the current processing rate. Additionally, a reward for finished items or served customers is modeled. The reward per unit is assumed to be constant or to be dependent on the current processing rate.

We present a general integrated decision model for optimizing the processing rates. First, closed form solutions are derived with a single decision on the processing rate under stationary conditions. Second, we analyze the system with time-dependent demand and multiple changes of the processing rates. The time-dependent behaviour is modeled with a stationary backlog-carryover (SBC) approach. Since the processing rates are the decision variables, we develop a new SBC-approach that calibrates the period length dependent on the result of the optimization.

A numerical study shows the reliability of the new approach. We show numerically that the decision on the processing rate in a current period may depend on future demand changes.

#### 2 - In-Line Sequencing in Automotive Production Plants - A Simulation Study

*Heinrich Kuhn, Marcel Lehmann*

Nowadays car manufacturers produce vehicles in a great variety of models on the same assembly line. This results in the stringent necessity of applying the concept of In-Line Sequencing (ILS) to parts and vehicles. Otherwise a huge amount of various parts has to be stored close to the assembly line. Delivering the main parts directly to the assembly line in the same sequence as the production schedule of the vehicles reduces inventory, produces greater assembly accuracy, and most of all lowers logistics costs.

The purchasing and logistics costs of parts however could be further reduced by predetermine the production sequence of the assembly line exactly for a longer time horizon, e.g., one week.

This is not an easy task since in general the assembly sequence originally planned gets into disorder during the preceding production processes of framing and painting. Restoring the original sequence is not possible in all instances and even a large sequencer in front of the final assembly line may not be able to rebuild the sequence.

The question therefore arises to which extent the assembly line sequence can be recreated in a real automotive assembly plant. We analyze the production facility of a major German automotive company in order to reveal stability potentials and to identify influencing factors for scrambling the original sequence.

We conduct a discrete event based simulation study, based on real world data for a period of half a year and measure the stability levels of different production stages. The study reveals different stability patterns depending on the underlying layout of the production facilities and the current state of the product life cycle. In addition, we analyze the recreation potential depending on the size of the ASRS.

#### 3 - Minimizing work-in-process inventory in dynamic Kanban systems

*Justus Arne Schwarz, Raik Stolletz*

The Kanban system is a widely spread inventory control mechanism for production systems, e.g., in the automotive and food industries. In these systems, the maximum work-in-process inventory (WIP) at each stage of the production is limited by the corresponding number of Kanban cards. The inventory between the stages is used to hedge against the randomness of the demand and of the production process. However, the traditional Kanban system is made for static environments. Dynamic changes in system characteristics can occur within a production system itself or may be induced by customers, e.g., because of seasonal patterns in demand. We consider a production system with serially arranged stations that serves a stochastic and time-dependent demand from a finished goods buffer. The goal is to minimize the expected value of the average WIP in the system over a finite planning horizon while guaranteeing a service level. We introduce a new

Proactive Kanban (PK) control, which features planned changes in the Kanban allocation at predefined points in time to account for future changes in the demand and the processing time distributions. The key decision for the PK control is the number of Kanban cards allocated over time. We show that for a single-stage system with exponentially distributed processing times, with time-dependent mean, and non-homogenous Poisson demand, the average backlogged orders decrease monotonically and the expected average WIP increases monotonically in the time-dependent Kanban allocation. To determine the optimal number of Kanban cards per stage and period in a serial line, a simulation-optimization approach is proposed. We find that the proposed PK control performs always better or equivalent compared to the traditional constant allocations.

## ■ TD-20

Thursday, 14:45-16:15 - RBM|4403

### Multiple Suppliers

Stream: Supply Chain Management  
Parallel session

Chair: Thomas Mellewigt

#### 1 - Newsvendor models with unreliable and backup suppliers

*Dimitrios Pandelis*

We develop and analyze newsvendor models with two suppliers. At first the retailer places an order to a primary unreliable supplier and reserves the capacity of a backup reliable supplier. Then, the retailer may exercise the option to buy any amount up to the reserved capacity after the delivered quantity from the primary supplier becomes known. In our work we analyze optimization models for several versions of the problem. We consider primary suppliers that are subject to random yield or random capacity and the cases when the option to buy from the backup supplier is exercised before or after the demand becomes known. We derive conditions on the reservation price that make the use of the backup supplier profitable and obtain properties of the optimal order and reservation quantities.

#### 2 - Finding the optimal fill rate and reorder point by simulating a periodic review stochastic inventory model with two supply modes

*Felix Zesch*

In a supply chain setting, the fill rate for articles in a warehouse is a common input parameter for finding optimal inventory parameters. In most cases, the fill rate is decided by management without considering quantitative analytics. We present and apply a methodology for approximating the optimal fill rate in inventory-production systems through discrete-event simulation and curve-fitting for a supply chain with an analytically intractable inventory problem. This supply chain features two supply modes, stochastic demand, stochastic lead time, no backlog and a periodic review (r,Q) policy. As shipments have a stochastic lead time, they are allowed to cross and overtake one another. The simulation runs create a series of cost observations for different fill rates, which can be approximated with a local polynomial regression approach. This yields the optimal fill rate and the corresponding inventory policy parameters for a given input parameter set. The simulation model is usable with different reorder policies and different distributions of both demand and lead times. We apply the model to a real-world business case and find that it is important to not only estimate the average demand for an article but also its standard deviation. Making such estimates makes it possible to find the optimal fill rate and reorder point. We discuss the effects of increased demand variation on inventory and transportation cost and explore the costs related to underestimating and overestimating demand variation. Finally, we compare the optimal reorder points for a supply chain with two supply modes to a supply chain with only one supply mode. Our findings are in line with current inventory theory.

#### 3 - Does the Effectiveness of Concurrent Sourcing in Reducing Opportunism Depend on the Internal/External Sourcing Balance?

*Thomas Mellewigt, Sarah Bruhs*

In this study we investigate the governance of concurrent sourcing and aim to make two central contributions: First, we investigate the effectiveness of output monitoring, behavior monitoring and solidarity to mitigate the risk of supplier opportunism in both singular and concurrent sourcing relationships. Second, we further refine our main predictions and distinguish between concurrent sourcing firms that procure most of their requirements for a given input from an outside supplier and firms that produce the larger part internally. Using primary data from the German machinery industry, we overall find support for our predictions regarding output monitoring and solidarity, but not behavior monitoring. Supporting our hypotheses, our results show that output monitoring is more effective at low levels and solidarity at high levels of internal production.

## ■ TD-21

Thursday, 14:45-16:15 - RBM|4404

### Advanced Flow Systems

Stream: OR in Engineering  
Parallel session

Chair: Fabian Gnegel

#### 1 - Polyhedral 3D Models for Natural Gas Compressors and Stations

*René Saitenmacher, Tom Walther, Benjamin Hiller*

In gas transmission networks, compressor stations are required to compensate for the pressure loss caused by friction in the pipes. They typically comprise several compressor machines that can be operated in different configurations, e.g., in serial or parallel. Modeling all physical and technical details of a compressor station involves a large amount of nonlinearity and discrete decisions, making it hard to use such models in the optimization of large-scale gas networks.

In this talk, we are first going to describe a modeling approach for the operating range of compressor machines, starting from a complicated physical reference model and resulting in a simple linear polyhedral representation in three dimensions: the throughput in terms of mass flow as well as the pressures at the inlet and outlet node of the machine. We will study some properties and the errors that are taken into account.

Moreover, combining the compressor machine polytopes according to the configurations allows us to obtain a non-convex disjunctive polyhedral representation of the operating range of an entire compressor station. We will introduce a preprocessing technique based on so-called Approximate Convex Decomposition in order to obtain relaxations for such feasible sets. These can be hierarchically refined when required and either be used to replace or to supplement the original model.

#### 2 - A new Approach for the Optimization of Booster Stations

*Jonas Benjamin Weber, Ulf Lorenz*

Typically, the supply pressure of water companies is not high enough to supply all floors of tall buildings e.g. skyscrapers with drinking water. To guarantee a continuous supply of all consumers so called booster stations are used to increase the pressure of the supplied drinking water for the demanded time-variant flow-rates. In technical terms these booster stations can be described as fluid systems consisting of interconnected components such as pumps, pipes, valves and other fittings.

Even for a relatively small set of possible components a variety of combination arises. Because of this combinatorial explosion, an algorithmic system synthesis approach is favorable. The main task for the algorithmic synthesis is to find topologies and control strategies with low costs which satisfy the consumer's demands at any time while obeying the general laws of fluid mechanics. As the problem instances reach a practically relevant size the common algorithmic approach of modeling the optimization problem as a mixed integer linear program (MILP) and solving it using standard MILP solvers fails to provide good solutions in reasonable time.

Therefore, we developed an approach to overcome this disadvantage. This approach is based on three key components. The optimization problem is modeled in two ways, a graph-based formulation and a MILP. Both views are used simultaneously while addressing the problem with heuristics from the primal and dual side to find good solutions as well as tight bounds. These heuristics make heavily use of problem

specific and technical knowledge. In a continuative step, we further combined both heuristics in a branch-and-bound algorithm to obtain optimal solutions.

### 3 - Mixed-Integer Linear Programming for a PDE-Constrained Dynamic Network Flow

*Fabian Gnegel, Armin Fügenschuh*

To compute a numerical solution of PDEs it is common practice to find a suitable finite dimensional approximation of the differential operators and solve the obtained finite dimensional system, which is linear if the PDE is linear. In case the PDE is under an outer influence (control), a natural task is to find an optimal control with respect to a certain objective. In this talk general methods and concepts are given for linear PDEs with a finite set of control variables, which can be either binary or continuous. The presence of the binary variables restricts the feasible controls to a set of hyperplanes of the control space and makes conventional methods inapplicable. We show that under the assumption that all additional constraints of the system are linear, these problems can be modeled as a mixed-integer linear program (MILP), and numerically solved by a linear programming (LP) based branch-and-cut method. If the discretized PDE is directly used as constraints in the MILP, the problem size scales with the resolution of the discretization in both space and time. A reformulation of the model allows to solve the PDE in a preprocessing step, which not only helps to significantly reduce the number of constraints and computation time, but also makes it possible to use adaptive finite element methods. It is further shown that the scaling of state-constraints with finer discretization can be reduced significantly by enforcing them in a lazy-constraint-callback.

## ■ TD-22

*Thursday, 14:45-16:15 - HFB|A*

### MCDM 5: Nonlinear Multiobjective Optimization

Stream: Decision Theory and Multiple Criteria Decision Making

*Parallel session*

Chair: *Kerstin Daechert*

#### 1 - A forward-backward method for solving vector optimization problems

*Sorin-Mihai Grad*

We present an iterative proximal inertial forward-backward method with memory effects based on recent advances in solving scalar convex optimization problems and monotone inclusions for determining weakly efficient solutions to convex vector optimization problems consisting in vector-minimizing the sum of a differentiable vector function with a nonsmooth one, by making use of some adaptive scalarization techniques.

#### 2 - Weight space decomposition for multiobjective convex quadratic programs

*Marco Milano, Kathrin Klamroth, Margaret Wiecek*

We consider convex quadratic programs with two or more conflicting objective functions and linear constraints. Efficient solutions, i.e., feasible solutions that can not be improved in one objective without deterioration in at least one other objective, can be obtained by weighted sum scalarizations, combining all objective functions using nonnegative weight vectors.

We extend the concept of the weight space decomposition by using an interrelation between efficient active sets and cells in the weight set. Using additionally the fact that the efficient active sets are connected, we derive a numerical algorithm for their computation, similar to Goh and Yang (1996). The method is illustrated at example problems with three objectives.

#### 3 - A bicriteria perspective on an L-penalty approach for solving MPECs

*Kerstin Daechert, Sauleh Siddiqui, Javier Saez-Gallego, Steven Gabriel, Juan Miguel Morales*

We focus on complementarity problems as a special case of MPECs. Even if all functions involved are linear the complementarity condition is non-convex and makes the problem challenging, in general. Several approaches exist in the literature that reformulate the complementarity condition, e.g., disjunctive constraints or Schur's decomposition. Recently also an L-penalty method was proposed in Siddiqui and Gabriel (2012).

In this talk we consider the latter approach from a bicriteria perspective. For linear problems we can easily indicate the solutions of the L-penalty formulation for all positive values of L. We can interpret parameter L as the trade-off between the original objective and the L-penalty term. The larger L the more emphasis is given to the penalty term. We present a new theorem which shows conditions under which this L-penalty approach finds a solution satisfying complementarity for sufficiently large L. We also demonstrate limitations of the proposed L-penalty formulation by indicating examples not satisfying these conditions for which a complementarity solution exists but can not be generated for any positive L.

## ■ TD-23

*Thursday, 14:45-16:15 - HFB|B*

### Congestion Games (i)

Stream: Game Theory and Experimental Economics

*Parallel session*

Chair: *Alexander Skopalik*

#### 1 - Approximation Algorithms for Unsplittable Resource Allocation Problems

*Antje Bjelde, Max Klimm, Daniel Schmand*

We study general resource allocation problems with a diseconomy of scale. In such problems, we are given a finite set of commodities that request certain sets of resources, e.g., paths in a network. The cost of each resource grows superlinearly with the demand for it, and our goal is to minimize the total cost of the resources. A natural distributed approach to solve these problems are local dynamics where in each step a single commodity switches its allocated resources whenever the new solution after the switch has smaller total cost over all commodities. These dynamics converge to a local optimal solution, and we are interested in quantifying the locality gap, i.e., the worst case ratio of the cost of a local optimal solution and a global optimal solution. We derive tight bounds on the locality gap both for weighted and unweighted commodities. By sacrificing an additional small factor, these locality gaps yield deterministic and combinatorial polynomial time algorithms that can be implemented in a distributed manner and provably approximate the optimal solution with approximation guarantee depending on the cost functions on the resources. Our performance guarantees for unweighted commodities asymptotically matches the approximation guarantee of the currently best known centralized algorithm due to Makarychev and Srividenko [FOCS 2014]. In contrast to their algorithm which is based on the randomized rounding of the solution of a convex programming relaxation, our algorithm is deterministic, combinatorial, and requires only local knowledge of the commodities.

#### 2 - Network Design Games with Bandwidth Competition and Selfish Followers

*Daniel Schmand, Alexander Skopalik, Carolin Tidau*

We study the following network design game. The game is set in two stages. In the first stage some players, called providers, aim to maximize their profit individually by investing in bandwidth on edges of a given graph. The investment yields a new graph on which Wardrop followers, called users, travel from their source to their sink through the network. The cost for any user on an edge follows market principles and is dependent on the demand for that edge and the supplied bandwidth. The profit of the providers depends on the total utilization of their edges, the current price for their edges and the bandwidth. We analyze the existence and uniqueness of Nash Equilibria for the providers in the described game. We provide insights on how competition between providers and the number of providers influence the total cost for the users.

### 3 - On 1.6-approximate pure Nash equilibria

Alexander Skopalik, Vipin Ravindran Vijayalaksh

Congestion games constitute an important class of games in which computing an exact or even approximate pure Nash equilibrium is in general PLS-complete. Caragiannis et al. [FOCS 2011] presented a polynomial-time algorithm that computes  $(2 + \epsilon)$ -approximate pure Nash equilibria for games with linear cost functions. We show that this factor can be improved to  $1.6 + \epsilon$  by a seemingly simple modification of their algorithm.

## ■ TD-24

Thursday, 14:45-16:15 - HFB|C

### Nonlinear Optimization 3

Stream: Control Theory and Continuous Optimization  
*Parallel session*

Chair: Mirjam Duer

#### 1 - Looking for the interset distance

Maksim Barketau, Erwin Pesch

We research the following problem. We are given two sets of vectors. All vectors of the first set are less or equal to all vectors of the second set that is the difference of each vector of the second set and each vector of the first set is in some convex cone  $K$  in the corresponding space. We try to find a separating vector for these two sets that is the vector that is less or equal to all vectors of the second set and simultaneously that is greater or equal than all vectors of the first set. We upperbound the least possible distance from the vector that less or equal to all vectors of the second set and the vector that is greater or equal to all vectors of the first set. We consider non-negative euclidean cone, ice-cream cone, semidefinite cone.

#### 2 - Projection method for minimization of polyhedral function over hypercube

Maxim Demenkov

We consider classical problem of nonsmooth optimization - minimization of a convex polyhedral function with interval constraints on variables.

Many algorithms are available for this problem, including subgradient methods and Nesterov's smoothing technique, as well as a simple reduction to the linear programming. Despite that, we investigate a new approach based on the conversion of this problem into finding an intersection between a special polytope (zonotope) and a line, proposed in [1] as a new kind of finitely convergent linear programming algorithm. Zonotope is an affine transformation of  $n$ -dimensional cube [2].

Our algorithm has strong geometric flavor and connected with projection methods [3]. Initially we suppose that we know an interior point of the zonotope on the line. In this case it is possible to derive a linearly convergent algorithm based on the bisection of interval between the interior point and a point outside the zonotope. At each iteration we project (using e.g. Frank-Wolfe or Nesterov fast gradient method) a point on the line in the middle of the interval onto the zonotope (which is equivalent to the projection onto a hypercube). Then, if the current point is outside the zonotope, we find an intersection between the boundary of a level set of the distance function passing through its projection, otherwise we take exactly this point to reduce the interval. In any case we reduce the length of the interval at least twice.

[1] Fujishige, S., Hayashi, T., Yamashita, K., Zimmermann, U.: Zonotopes and the LP-Newton method. *Optimization and engineering*, 10, 193-205 (2009). [2] Ziegler, M.: *Lectures on polytopes*. Springer-Verlag, New York, 1995. [3] Escalante, R., Raydan, M.: *Alternating projection methods*. SIAM, 2011.

#### 3 - A factorization method for completely positive matrices based on alternating projections

Mirjam Duer, Patrick Groetzner

Many combinatorial and nonconvex quadratic problems can be reformulated as linear problems over the copositive and completely positive cones. However, checking membership of a matrix in any of these two cones is an NP-hard decision problem. A certificate for a matrix to be completely positive is its nonnegative factorization.

We present a method to derive such a factorization using an alternating projection method between certain nonconvex sets. Alternating projection is a common algorithm to find points in the intersection of two convex sets. This method has recently been extended to alternating projection on manifolds and on more general nonconvex sets, as used in our approach. Our method provides factorizations for almost all matrices in a few seconds.

## ■ TD-25

Thursday, 14:45-16:15 - HFB|D

### Energy-oriented scheduling

Stream: Energy and Environment  
*Parallel session*

Chair: Magнус Fröhling

#### 1 - Energy-efficient multi-objective scheduling

Damian Braszczyk, Andreas Dellnitz, Andreas Kleine, Jonas Ostmeier

In classical scheduling problems, time goals are the most common objectives. Multi-objective scheduling approaches usually include additional cost aspects. The expansion of renewable energies influences energy market prices increasingly and, hence, the production costs as well - this the more the more energy-intensive a production process is. Consequently, in scheduling problems time goals and, in addition, energy costs should be considered. This is subject of so-called energy-efficient scheduling.

Furthermore, besides the concept of energy efficiency, sustainability plays an important role in the economic context. Often sustainability of a production process is measured via its carbon emissions. Therefore, this contribution wants to create twofold transparency by addressing the following questions: What is the meaning of energy efficiency and sustainability in the field of scheduling theory? What is an appropriate mathematical model to combine both perspectives? The discussion of these questions leads to a multi-objective scheduling problem with three conflicting goals - time, costs and emissions. Finally, a small numerical example demonstrates the applicability of the new approach.

#### 2 - Energy-oriented scheduling of parallel machines considering peak demand charges and labor costs

Lukas Strob, Thomas Volling

The trend towards an increasing share of renewables leads to large fluctuations in prices for electric energy. These fluctuations are a chance for industrial firms to lower their electricity bill if they manage to shift energy intensive operations to periods with low energy prices. However, there are potential conflicts with other costs. Shifting operations could increase demand charges, which are - in addition to energy charges - typically part of the electricity bill. Additionally, shifting operations could result in increased labor costs due to a lower productivity or unfavorable working time models. Determining energy-oriented schedules therefore requires an integrative perspective considering these conflicts between energy related costs and labor costs.

We propose a mathematical model (MILP) for the energy-oriented scheduling problem with parallel machines. The model comprises time-dependent labor costs and energy related costs while simultaneously determining optimal job assignments, job sequences and machine operation modes. We consider a common electricity tariff structure that consists of time-varying energy charges as well as a peak load-dependent demand charge. Drawing upon an application-oriented numerical example, we compare the performance of the model with a conventional scheduling approach that only minimizes labor costs. The results indicate that significant cost reductions can be achieved under a wide range of conditions. The potential is especially pronounced if the degree of capacity utilization is low to medium and job durations are short.

## ■ TD-26

Thursday, 14:45-16:15 - HFB|Senat

### Behavioral Operations Management (i)

Stream: Game Theory and Experimental Economics

*Parallel session*

Chair: *Andreas Fügener*

#### 1 - Performance of inventory policies under scarcity - a behavioral perspective

*Sebastian Schiffels*

Simple inventory policies are widely used in practice since they are easily applicable. A well-known behavioral phenomenon related to the inventory of a retailer, but often neglected in inventory management, is the scarcity effect, i.e. the demand for a product increases if the inventory is low. Our research addresses the question of how scarcity behavior impacts the performance of two common classes of inventory policies - periodic and continuous policies. Since the fill rate, i.e. the fraction of demand that is satisfied directly from stock on hand, is the most common way of measuring service, we configure both inventory policies in order to achieve the same target fill rate. To investigate the influence of the scarcity effect on the two policies and vice versa, we set up an experiment with human decision makers acting as buyers. For both policies, we consider a treatment with a high fill rate and a treatment with low fill rate. Our preliminary results indicate that scarcity behavior can already be observed in settings with few buyers and a theoretical stock-out probability close to zero, verifying that it is a strong effect and furthermore, we find that scarcity behavior negatively impacts the performance of both inventory policies. Finally, our results show that continuous policies perform significantly better compared to periodic policies in the setting with a low fill rate, a finding which should be taken into account when determining which inventory policies to use.

#### 2 - A behavioral investigation of the effect of strategic buckets in project selection

*Andreas Fügener, Sebastian Schiffels, Ulrich Thonemann*

This study discusses the selection of risky and non-risky projects. In line with the literature we show that peoples risk aversion leads to an underrepresentation of risky projects in a simplified project selection process. We analyze whether voluntary and mandatory strategic buckets may help to overcome this issue. A strategic bucket defines a sub-budget for a specified class of projects. The underrepresentation of risky projects is a well-known issue in new product development/project management practice and research. The use of strategic buckets has been proposed in practice and tested with theoretical models in the management science literature. A behavioral investigation of project selection and of strategic buckets is still open. In a preliminary experimental study subjects had to choose six projects from a list of twelve projects. Six of the projects were riskless, while the remaining six projects could fail with a probability of 50%. A portfolio maximizing expected value includes three risky and three riskless projects. The preliminary study shows that a) risky projects were underrepresented in portfolios without strategic buckets, and that b) strategic buckets could increase the ratio of risky projects. Thus, we demonstrate that risk aversion on the decision maker level may to some extent explain the underrepresentation of risky projects. Our results further indicate that simple strategic buckets help to overcome this issue. It is noticeable that voluntary buckets achieve the same results.

#### 3 - Behavioral Responses to Disruptions in the Multi-Armed Bandit Model

*Abdolhossein Ghayazi, Mirko Kremer, Fabian Sting*

How do human decision makers respond to changing business landscapes? Toward answering that question we investigate the well-studied multi-armed bandit model—yet enriched with disruptions, i.e., changes in the stochastic processes that yield the arms' payoffs. We compare normative results from comprehensive simulation studies with behavioral results from lab experiments. Our findings fundamentally challenge some of the existing theoretical knowledge on exploration-exploitation trade-off in turbulent environments.



## Friday, 9:00-10:30

### ■ FA-01

Friday, 9:00-10:30 - WGS|101

#### Inventory Routing

Stream: Logistics and Freight Transportation

Parallel session

Chair: *Sebastian Malicki*

##### 1 - A decision support system for last-mile distribution of perishables in e-grocery operations

*Christian Fikar*

This work introduces a decision support system to investigate dynamic last-mile distribution of organic fresh fruits and vegetables in urban e-grocery operations. It facilitates an agent-based simulation to model uncertainty in demand and food quality with optimization procedures to perform routing and scheduling decisions. Various food quality models are implemented to calculate food spoilage based on scheduled delivery routes as well as on varying storage and transport temperatures. A store-based attended home delivery concept is investigated, i.e. the e-grocery provider operates multiple stores from which products are picked up and delivers these products directly to the customers. Consequently, throughout the day of operation, the provider has to decide which specific products located at one of the provider's locations are shipped to a customer and further has to select a delivery vehicle, route and time. Food quality functions and various picking strategies are considered to analyze the impact of jointly investigating picking and routing decisions. Computational experiments based on an omnichannel e-grocery provider operating in Vienna, Austria, and 48 food products are presented. Results highlight the importance of considering food specific characteristics in e-grocery distribution. Trade-offs between minimizing travel distances and maximizing food quality at the time of delivery are investigated as well as impacts on store utilization to facilitate efficient e-grocery operations and potentially decrease food waste.

##### 2 - Inventory Routing: Consistency and Split Deliveries

*Emilio Jose Alarcon Ortega, Michael Schilde, Karl Doerner, Sebastian Malicki*

We present a new methodology to deal with the inventory routing problem in beer businesses where consistency in delivery times is an important aspect for customer satisfaction. We propose a mathematical model for the Consistent Inventory Routing Problem with Time-Windows and Split Deliveries (CIRPTWSD). Although the consumption of beer per year is quite stable, the demands and characteristics of the customers are really diverse (bars, restaurants, stands...). We include the possibility for split deliveries in the formulation to cover the case of temporary high demands caused by special events such as sports events or music festivals. This creates the need of delivering commodity with more than one vehicle. Our model assumes deterministic and constant demands during each of the time periods. We also propose a metaheuristic based on the concept of Adaptive Large Neighborhood Search (ALNS) to obtain efficient solutions for large real world instances. First, an initial solution is constructed using a cheapest insertion methodology followed by a local search to avoid single-customer-routes and to balance initial inventory levels. We then apply ALNS to the obtained solution. We developed several destroy and repair operators that target certain aspects of the specific problem in order to obtain good routing and inventory plans. These operators not only deal with distance and inventory costs but, moreover, with inconsistency in the arrival times to the customers. Finally, we present computational results obtained by applying our exact method as well as the proposed metaheuristic to a benchmark set of artificial instances and a set of instances based on real world consumption data.

##### 3 - Inventory Routing: Setting Safety Stock under Stochastic Demands

*Sebastian Malicki, Stefan Minner, Michael Schilde*

The stochastic inventory routing problem (IRP) merges vehicle routing and inventory management under uncertainty. It is relevant for vendor managed inventory (VMI), a practice used by many businesses in order to reduce inventory costs as well as shortages through integrated planning. The IRP requires three decisions to be made simultaneously, i.e. when to deliver to each customer, which quantity to deliver, and how to

combine these decisions efficiently into delivery routes. We consider the stochastic, single-product, multi-period, single-stage IRP with time windows and serially correlated demands. We introduce a mixed integer linear programming (MILP) formulation with dynamic lot-sizing and safety stock planning. Furthermore, we propose a heuristic which is based on the well-known savings algorithm extended with inventory savings. We evaluate the method by solving adapted instances from literature as well as by comparing our results on real-world data sets. We assess the effect of time windows as well as the cost of obtaining service levels and of ignoring correlation. Moreover, we benchmark the heuristic solution quality by comparison with the exact MILP solution for instances which are solvable in a reasonable amount of time. The results show that the proposed approach performs very well in terms of solution quality and computation time.

### ■ FA-02

Friday, 9:00-10:30 - WGS|102

#### Optimization Applications

Stream: Software Applications and Modelling Systems

Parallel session

Chair: *Roland Wessály*

##### 1 - Modeling uncertainties in supply chains

*Christian Timpe*

According to many sources, volatility of markets has increased during recent years. Reasons for that are, among others, political disturbances, technological advances and increasing customer expectations. For supply chain planning, this means increasing complexity, while the pressure on cost and inventories remains high. While you will find the basic methods for consumption-driven and forecast-driven planning in all major planning systems, in practice often a mixture of those two approaches is needed, as the demand fluctuations observed will at least partly be explainable by statistic models, and a safety stock is kept for the forecast errors. Despite that, the models used for computing safety stocks and production plans are usually set up completely independent, e.g. the well-known basic safety stock formulas assume a constant leadtime, while in reality the leadtime is a consequence of the resource load, and vice versa, the projected resource load should take the potential necessity of a safety-stock refill into account. This lack of a coherent approach is of particular importance in the process industry, where often many products compete for both production resources and storage space. In this presentation, we will present several examples from BASF, some of which we worked on in university cooperations.

##### 2 - Exam scheduling at United States Military Academy West Point

*Frederik Proske, Robin Schuchmann*

Each term the United States Military Academy (USMA) needs to schedule their exams. About 4000 cadets taking 5 - 8 exams each, need to be placed in 11 exam periods subject to several soft and hard constraints. Due to the short time frame in which the exams take place, a feasible solution in the sense that no cadet takes more than one exam per period cannot be obtained with a single exam version per course. So called makeups, alternative exams in another period, solve this problem. In order to reduce the extra work for instructors that must prepare those alternative exams, the number of makeups should be minimized. Makeups are also used to improve secondary objectives which occur at USMA West Point like the number of consecutive exams per cadet or to avoid that cadets take exams in certain periods (e.g. because of sport events they should attend). We consider two solution approaches: an integer programming approach using decomposition strategies and a nonlinear approach based on LocalSolver. We report numerical experiments for both methods based on real world data from the USMA West Point.

##### 3 - Generic Construction and Efficient Evaluation of DAEs with Flow Network Structure and Their Derivatives in the Context of Gas Networks

*Tom Streubel, Christian Strohm, Philipp Trunschke, Caren Tischendorf*

The dispatchers at a transmission network operator (TSO) influences the gas network state by changing settings for controllable network equipment such as valves and compressors. The effect on the overall system is then evaluated by detailed simulation. The ultimate goal is the combination of gas network optimization with a subsequent simulation based verification and adjustment into a back and forth iteration.

We deal with the simulation step. Depending on modeling decisions and after spatial discretization of pipe equations, the simulation problem can be represented as a system of differential algebraic equations (DAE). Many DAE solvers (e.g. sundials, dassl, etc.) expect the DAE to be solved in form of a black-box program. The black box provides the residual output of the system function and one or two linear operators of partial derivatives for given input. We want to present our experiences and implementation approaches to provide these evaluation procedures generically from the network structure. The derivative operators come naturally in a compressed-sparse-row format (CSR), but are composed of dense derivatives of all the individual model functions of all elements in the network. Their construction and management can be automated. Whereby management means detecting sparsity pattern, initial allocation, reuse and reallocation due to live manipulation of the networks topology and state dependent events. This allows the individual treatment of every element and the combination of various differentiation strategies such as automatic differentiation, analytic formulas and finite differences.

#### 4 - Gigabit at home - How mathematics makes the fiber rollout more efficient!

*Roland Wessály*

Fiber-to-the-home (FTTH) is world-wide one of the hottest infrastructure topics. Since the demand for higher and higher bitrates increases rapidly, telecommunications network operators are deploying fiber down to the customers premises.

Such an infrastructure rollout is very expensive. Just in Germany the estimated investment is about 80 billion Euro. Therefore, it is utmost importance to find the right balance between investments and revenues.

In this presentation we will give an overview how atesio supports network operators to solve a bunch of difficult FTTH network design problems on using an approach which is based at its core on various mixed-integer linear programming models. We will also demonstrate how this helped in projects with network operators to improve the business case significantly.

## ■ FA-03

*Friday, 9:00-10:30 - WGS|103*

### Warehouse Management

Stream: Logistics and Freight Transportation  
*Parallel session*

Chair: *David Boywitz*

#### 1 - Active repositioning of storage units in Robotic Mobile Fulfillment Systems

*Marius Merschformann*

In our work we focus on Robotic Mobile Fulfillment Systems in e-commerce distribution centers. These systems were designed to increase pick rates by eliminating unproductive travel time, while ensuring that orders are shipped as fast as possible. This is achieved by employing mobile robots bringing movable storage units (so-called pods) to pick and replenishment stations as needed, and back to the storage area afterwards. One advantage of this approach is that repositioning of inventory can be done continuously, even during pick and replenishment operations. This is primarily accomplished by bringing a pod to a storage location different than the one it was fetched from, a process we call passive pod repositioning. Furthermore, this can be done by explicitly bringing a pod from one storage location to another, a process we call active pod repositioning. In this work we conduct a simulation-based evaluation to investigate the effects of control mechanisms employing the latter technique and compare them to the passive one. By this, we give first insights about the trade-off occurring when using robots for active repositioning, because less robots are available for picking and replenishment.

#### 2 - Order picking with heterogeneous technologies: An integrated article-to-device assignment and manpower allocation problem

*Ralf Gössinger, Grigory Pishchulov, Imre Dobos*

Current order picking technologies are characterized by different degrees of automation in a range from completely manual to highly automated processing. Which degree can be chosen, primarily depends on

the characteristics of the articles to be picked (e.g. weight, shape, size). Some articles can be picked with all technologies; some may require either rather manual or rather automated technology. Irrespective of the automation level, order picking remains a labor-intensive process. Merely the required worker qualification changes with increasing level of automation — from predominantly manual skills to a balanced mix of manual and cognitive skills. Hence the decision to apply specific technologies and the decision on labor utilization are interdependent in warehouses with a heterogeneous set of articles, where order picking has to be performed by different technologies. To simplify managerial decision-making and reduce computational effort, both problems can in fact be tackled in an isolated way, by successively applying the respective planning approaches. However, this would not exploit synergies of coordinated problem solutions, due to the existing interdependencies. In the intended contribution we develop a planning approach that integrates both decision problems and therefore coordinates their solutions to a maximum extent — by utilizing a flexible assignment of articles to order picking devices and a flexible allocation of manpower to picking zones. In order to capture the value of coordination, we conduct numerical experiments with the integrated and sequential planning approaches using real data and hypothetical data of a pharmaceutical wholesaler. The comparison refers to the performance of both, the order picking system and the planning approaches.

#### 3 - Motion and Layout Planning in a Grid-Based Early Baggage Storage System

*Altan Yalcin, Achim Koberstein, Kai-Oliver Schocke*

Grid-based storage systems consist of many adjacent equi-sized rectangular cells arranged in a rectangular grid. Cells are either empty or occupied by a storage item. Items are stored on conveyors and are movable simultaneously and independently into the four cardinal directions. This technology allows for very dense storage. Previous research on grid-based storages has mainly focused on retrieval performance analysis of a single storage item. We contribute efficient storage and retrieval algorithms for a large number of storage items using multi-agent routing algorithms. We evaluate our algorithms in a case study designing and analysing a grid-based early baggage storage system at a major German airport.

#### 4 - Robust storage assignment in stack- and queue-based storage systems

*David Boywitz, Nils Boysen*

In stack- and queue-based storage systems, items stored behind the foremost position are only accessible once all blocking items have been removed. A prominent example are deep-lane storage systems, which are often applied in the refrigerated warehouses of the food industry. The price for the high space utilization of these compact storage systems is, thus, a larger retrieval effort whenever items are not properly stored according to increasing due dates. Due dates, however, are often bound to uncertainties, e.g., due to untimely arrivals of the outbound vehicles picking up the stored items. This paper introduces a new way to derive robust storage assignments, such that excessive retrieval effort is avoided in spite of due date uncertainty. Specifically, we aim to maximize the minimum time difference between due dates of items dedicated to different vehicles and stored in the same stack or queue. The resulting optimization problem is defined, computational complexity is proven, and suited solution procedures are derived. Furthermore, a simulation study investigates whether our novel storage assignments are indeed more robust against unforeseen delays than previous approaches.

## ■ FA-04

*Friday, 9:00-10:30 - WGS|104*

### Random Keys and Integrated Approaches

Stream: Metaheuristics  
*Parallel session*

Chair: *Franz Rothlauf*

#### 1 - A Biased Random-Key Genetic Algorithm for the Liner Shipping Fleet Repositioning Problem

*Daniel Müller*

As liner carriers adjust their network of cyclical routes throughout the year, vessels must be moved from one route to another in a process called fleet repositioning. Although heuristics such as simulated annealing and reactive tabu search have been used to solve the liner shipping fleet repositioning problem (LSFRP), there still is room for improvement considering the gap to the optimal solution and the computational time. We propose solving the LSFRP with a biased random-key genetic algorithm (BRKGA), as it can more effectively avoid infeasible solutions than the currently available heuristics. The inherent learning mechanism of the algorithm helps to identify solutions with good objective values. We perform a computational analysis of this approach on publicly available LSFRP instances and compare it to the existing simulated annealing and hybrid reactive tabu search approaches. Furthermore, we integrate this approach in a previously presented decision support system.

## 2 - Generalized Random Key Algorithms for Heuristic Optimization

*Kevin Tierney*

We show how continuous optimization heuristics can be used for finding solutions to discrete optimization problems through the use of a so-called random key. A random key is a sequence of continuous values between 0 and 1 that are used for decision making within a heuristic construction algorithm. Random keys have been used with success in (biased) random key genetic algorithms ((B)RKGAs) to guide heuristic construction processes for discrete and continuous optimization problems, thus allowing genetic algorithms to be applied to problems where effective recombination and mutation operators are either difficult to create or too expensive to use in practice. We show that the BRKGA is a special case of a wider class of biased-random key approaches that we call generalized random key algorithms (GRKAs). GRKAs allow existing continuous optimization metaheuristics, such as the covariance matrix adaptation evolutionary strategy or particle swarm optimization, to solve discrete problems in a solution construction process without rounding decision variables. We perform an experimental analysis showing the benefits of GRKAs over BRKGAs and other construction techniques on several different operations research problems.

## 3 - The inola AOC - a proved and tested self-learning metaheuristic for optimization in logistics and transportation

*Thomas Scheidl*

The ever-expanding requirements in our present-day society provide increasing challenges for today's software solutions. Lots of data with complex models and relations shall be processed as fast as possible and should lead to most accurate solutions. People who are responsible for processes need at least support in their decision-making which leads to an increasing demand on optimization in all sectors. This lecture shows how the inola Optimization Core, a self-learning, metaheuristic optimization technology, based on object-oriented programming, makes this possible. The technology integrates domain-specific-knowledge, enabling it to act instinctively, thus being effective like the decision maker himself. Additionally, it is also possible to embed well-explored solution-strategies. The optimization system learns from the on-going-optimization process, identifies good working solution-strategies and thereby influences the further completion. This leads to consistently better and fast-available solutions. Results can be requested at any time in the optimization process which leads to an interference-free process flow for all users. Concluding, two practical examples and results from warehouse logistics and integrated block duty planning in public transport are presented to show how to use this technology, how it can be integrated into other systems and how the user can be assisted optimally.

## 1 - A Novel SDP Relaxation for the Quadratic Assignment Problem using Cut Pseudo Bases

*Maximilian John, Andreas Karrenbauer*

The quadratic assignment problem (QAP) is one of the hardest combinatorial optimization problems. Its range of applications is wide, including facility location, keyboard layout, and various other domains. The key success factor of specialized branch-and-bound frameworks for minimizing QAPs is an efficient implementation of a strong lower bound. We propose such an implementation that transform the QAP to a different lower-bound-preserving quadratic program. The key concept of this transformation is the notion of cut pseudo bases, which we introduce in this paper. The cut pseudo bases allow for small semidefinite programming relaxations, leading to an efficient generation of lower bounds for the original problem. This whole transformation is self-tightening in a branch-and-bound process.

## 2 - Optimizing Special Character Entry: the Case of the French Keyboard Standard

*Anna Maria Feit, Antti Oulasvirta*

We present the optimization of the new French standard for keyboard layouts. The typical French keyboard layout made it overly complicated or even impossible to type all French characters, punctuation marks, and other symbols. The goal of this new standard was to enable and facilitate the correct spelling of French, and allow the entry of symbols common in programming languages, mathematical expressions, and other European languages. Therefore, we had to assign over 115 characters to 148 slots on the keyboard, optimizing their placement with respect to each other and to the numbers (0-9) and non-accentuated letters (a-z) that were kept unchanged. In interaction with an expert committee, we identified four objectives: input performance and ergonomics, similarity to the prior keyboard, and coherent placement of similar symbols. We collected extensive performance data, language statistics, expert ratings on character similarities, and ergonomic scores to implement and solve a multi-objective quadratic assignment problem. In an iterative process, we computed and adapted a range of solutions in interaction with language experts. The resulting design unifies mathematical bounds with expert opinions and constraints. The new French keyboard layout is the first modern standard where computational optimization methods were used in interaction with domain experts to implement an optimal keyboard design.

## 3 - Layout Design with Combinatorial Optimization

*Niraj Ramesh Dayama, Antti Oulasvirta*

Organization of user-actionable elements is a basic tenet of layout design. This topic has been extensively studied in the context of element size, orientation, color, location and other parameters. The current paper proposes a mathematical model that optimizes the layout of elements on a canvas. The combinatorial optimization model is implemented in terms of a mixed integer linear program that can be solved via standard commercial solvers. A broad range of design objectives (including grid alignment, clutter reduction, symmetry/balance, etc.) are addressed within this model; further the implementation is flexible enough to cater to other additional objectives and constraints as required by the designer.

## 4 - Combinatorial Optimization in User Interface Design

*Antti Oulasvirta*

Optimization methods have revolutionized almost every field of engineering design, so why not user interface design? I review progress and challenges in model-driven user interface optimization. The challenge is to incorporate predictive models of human perception, behavior, and experience in the objective function to anticipate users' responses to computer-generated designs. Examples are presented in the design of input devices, menus, web pages, and visualizations.

## ■ FA-05

*Friday, 9:00-10:30 - WGS|104a*

## Discrete Optimization for User-Interface Design (i)

Stream: Discrete and Integer Optimization

*Parallel session*

Chair: *Andreas Karrenbauer*

Chair: *Antti Oulasvirta*

## ■ FA-06

*Friday, 9:00-10:30 - WGS|105*

## Assignments and Matchings

Stream: Graphs and Networks

*Parallel session*

Chair: *Isabel Beckenbach*

### 1 - An Empirical Study on Online Frequency Assignment Problem (FAP)

Selin Bayramoglu, Berkin Tan Arici, Ali Özgür Çetinok, Tinaz Ekim

Online FAPs arise in wireless networks in various forms. In this work, we consider traveling radiophone users as communication agents. Calls occurring below a certain distance from each other cause interference if they use the same frequency. Given a set of available frequencies, we need to assign a frequency to each call as soon as it happens while avoiding interference. If no frequency can be assigned, the call is dropped. The objective is to minimize the number of dropped calls. A snapshot of the dynamic network can be shown by a graph where vertices represent the locations of outgoing calls and edges are present whenever calls are close enough to each other to cause interference. Then, the objective is to color this graph with a minimum number of colors where no two adjacent vertices get the same color. The problem has an online nature as vertices and edges appear/disappear over time. The online graph coloring problem has been widely studied from a theoretical point of view where the competitive ratios of various algorithms have been analyzed. However, to the best of our knowledge, few computational study has been conducted on this topic. Here, we present and compare experimental results of various online graph coloring algorithms. In addition, we develop an IP model to find optimal solutions and compare with our heuristic results. It should be noted that, unlike many exact solutions to which online algorithms' results are compared, the solution the IP model returns is realizable when the instance is considered online. That is if a frequency is available at the time a call has arrived, we can't drop this call, as expected in an online framework, even if this allows us to ensure more calls in the future.

### 2 - k-Budgeted Matching Problems

Martin Comis, Christina Büsing

The k-budgeted matching problem is a weighted matching problem with k different edge cost functions. For each cost function, a budget constraint requires that the accumulated cost does not exceed a corresponding budget.

When k is part of the input, we show that the k-budgeted matching problem is strongly NP-hard on bipartite graphs with uniform edge weights, costs and budgets using a reduction from (3,B2)-SAT.

For fixed constant k, we propose a dynamic program for series-parallel graphs with pseudo-polynomial runtime. As an extension, we show how this algorithm can be used to solve the problem on trees using a simple graph transformation.

Realizing that both these graph classes have a bounded treewidth in common, we show how one can apply dynamic programming to tree decompositions in order to obtain a pseudo-polynomial algorithm for the much larger class of graphs with bounded treewidth.

### 3 - Matchings in hypergraphs

Isabel Beckenbach

We give an overview about matching theory in hypergraphs which generalize graphs by allowing edges to contain more than two vertices. Finding a maximum size or weight matching, or deciding whether a hypergraph has a perfect matching becomes NP-hard and there does not exist a nice matching theory as for graphs. Therefore, we restrict our attention to different classes of hypergraphs with some additional structure generalizing different aspects of bipartite graphs to hypergraphs. It turns out that results and methods used for bipartite graphs carry over to some of these classes; for example König's Theorem, and Hall's Theorem. Furthermore, we discuss a matching algorithm for a restricted class of hypergraphs. This algorithm is based on a generalization of the network simplex algorithm to flows on hypergraphs.

### 1 - SCIP-Jack: a solver for Steiner Tree problems in graphs and their relatives

Thorsten Koch, Daniel Rehfeldt, Stephen Maher, Gerald Gamrath, Yuji Shinano

The Steiner tree problem in graphs is a classical problem that commonly arises in practical applications as one of many variants. While often a strong relationship between different Steiner tree problem variants can be observed, solution approaches employed so far have been prevalently problem-specific. In contrast, we will present a general-purpose solver that can be used to compute optimal solutions to both the classical Steiner tree problem and many of its variants without modification. In particular, the following problem classes can be solved: Steiner Tree in Graphs (STP), Steiner Arborescence (SAP), Rectilinear Steiner Minimum Tree (RSMTP), Node-weighted Steiner Tree (NWSTP), Prize-collecting Steiner Tree (PCSTP), Rooted Prize-collecting Steiner Tree (RPCSTP), Maximum-weight Connected Subgraph (MWCSP), Degree-constrained Steiner Tree (DCSTP), Group Steiner Tree (GSTP), and Hop-constrained Directed Steiner Tree (HCDSTP). This versatility is achieved by transforming various problem variants into a general form and solving them by using a state-of-the-art MIP-framework. The result is a high-performance solver that can be employed in massively parallel environments and is capable of solving previously unsolved instances. SCIP-Jack has participated in the 11th DIMACS Implementation Challenge and been demonstrated to be the fastest solver in two categories. Since the Challenge tremendous progress regarding new solving routines such as preprocessing and heuristics was made, resulting in a reduction of the run time of more than two orders of magnitude for many instances.

### 2 - Polyhedral Symmetry Handling Techniques Exploiting Problem Information

Christopher Hojny, Marc Pfetsch

In this talk, we present polyhedral symmetry handling techniques that exploit not only symmetry but also problem information. The aim of treating both kinds of information simultaneously is to obtain tighter cutting planes than in an approach that does not use problem information. For example, partitioning orbitopes are discussed in the literature. These polytopes can handle color symmetries in graph coloring problems efficiently by exploiting that each node of a graph is assigned exactly one color. However, graph automorphisms cannot be handled by these polytopes.

To handle graph automorphisms that act on cliques of G, we introduce packing/partitioning symresacks which exploit problem specific packing (or partitioning) constraints and symmetry. For both kinds of polytopes, we derive small integer programming formulations with constant size coefficients, and we derive complete linear descriptions for a specific class of permutations. Both formulations allow us to handle symmetries efficiently, and we present numerical results that show the positive effect of packing/partitioning symresacks on symmetric binary programs.

### 3 - Experiments with Conflict Analysis in Mixed-Integer Programming

Jakob Witzig, Timo Berthold, Stefan Heinz

Conflict analysis plays an import role in solving Mixed-Integer Programs (MIPs) and is implemented in most major MIP solvers. The analysis of infeasible nodes has its origin in solving satisfiability problems (SAT). In addition to the technique known from SAT (conflict analysis), dual information obtained from solving Linear Programms (LPs) can be used to render infeasibility (dualray analysis). In this talk, we discuss both techniques in more detail. We present computational experiments conducted within the non-commercial MIP solver SCIP.

## ■ FA-07

Friday, 9:00-10:30 - WGS|106

### Computational Mixed-Integer Programming 4

Stream: Discrete and Integer Optimization  
Parallel session

Chair: Ambros Gleixner

## ■ FA-08

Friday, 9:00-10:30 - WGS|107

### Electric Vehicles: Challenges

Stream: Traffic, Mobility and Passenger Transportation  
Parallel session

Chair: Dennis Huisman

## 1 - Forecasting Energy Consumption for Safety-Assessed In-Car Applications

*Dominik Grether, Sebastian Hudert*

The rollout of electric vehicles is an ongoing, but challenging task. The most critical technical challenge at this point is still the limited range of electric vehicles. To this end, in-car applications are developed assisting drivers in saving energy. In order to achieve this goal, these applications heavily rely on information and forecasts on the state of the traffic system and traffic patterns.

This work tackles both aspects - the development and seamless roll-out of in-car applications and the forecasting of traffic patterns as a technical basis for these applications. The former goal is achieved via the concept of an automotive app-store, delivering vendor agnostic in-car apps combined with a secure runtime environment to execute such apps within the vehicle. The resulting ecosystem for automotive-apps demonstrates how safety of in-car applications can be assessed virtually using an open development environment even suited for industry certification.

The latter goal addresses how the state of the traffic system can be predicted by coupling multi-agent transport simulations. The prediction is subsequently used to estimate energy consumption of electric vehicles. The case of electric car sharing fleets is used to demonstrate our approach. On top of the estimates optimization models are developed to improve user experience.

## 2 - Electric Vehicle Scheduling under extreme conditions at the police

*Kerstin Schmidt, Felix Saucke, Thomas Spengler*

As a pioneer and role model in society, the police integrate electric vehicles into their fleets. This new generation of patrol cars reduces environmental pollution and has lower energy costs compared to conventionally fueled vehicles. Moreover, the electric vehicles are nearly noiseless, leading to advantages for some operation strategies for the police. However, the challenges related to the use of electric vehicles are small distance ranges, long recharging times, as well as limited availability of the recharging infrastructure. Furthermore, in police use the vehicles have to be nearly 100 % available in the service and patrol duty, while the place and time of usage as well as travel distances are uncertain. To deal with these challenges, a decision support for electric fleet operation under extreme conditions and special requirements at the police is needed. In this contribution, we present an extension of the Electric Vehicle Scheduling Problem (E-VSP) for the police. The model aims to analyze and evaluate the fleet composition under different objectives. On the one hand, a high availability of electric vehicles has to be ensured and on the other hand, the number of vehicles in the fleet should be minimized. To illustrate the benefits and challenges of our approach, a numerical example will be presented.

## 3 - The Vehicle Rescheduling Problem with Retiming

*Dennis Huisman, Rolf Van Lieshout, Judith Mulder*

When a vehicle breaks down during operation in a public transportation system, the remaining vehicles can be rescheduled to minimize the impact of the breakdown. In this presentation, we discuss the vehicle rescheduling problem with retiming (VRSPRT). The idea of retiming is that scheduling flexibility is increased, such that previously inevitable cancellations can be avoided. To incorporate delays, we expand the underlying recovery network with retiming possibilities. This leads to a problem formulation that can be solved using Lagrangian relaxation. As the network gets too large, we propose an iterative neighborhood exploration heuristic to solve the VRSPRT. This heuristic allows retiming for a subset of trips, and adds promising trips to this subset as the algorithm continues. Computational results indicate that the heuristic performs well. While requiring acceptable additional computation time, the iterative heuristic finds improvement over solutions that do not allow retiming in one third of the tested instances. By delaying only one or two trips with on average 4 minutes, the average number of cancelled trips is reduced with over 30 percent.

## 1 - The multi-stripe travelling salesman problem

*Eranda Cela, Vladimir Deineko, Gerhard Woeginger*

In the classical Travelling Salesman Problem (TSP), the objective function sums the costs for travelling from one city to the next city along the tour. In the  $q$ -stripe TSP with  $q$  larger than or equal to 1, the objective function sums the costs for travelling from one city to each of the next  $q$  cities along the tour. The resulting  $q$ -stripe TSP generalizes the TSP and forms a special case of the quadratic assignment problem. We analyze the computational complexity of the  $q$ -stripe TSP for various classes of specially structured distance matrices. We derive negative (NP-hardness) results as well as a number of positive results. One of our main results generalizes a well-known theorem of Kalmanson from the classical TSP to the  $q$ -stripe TSP.

## 2 - Convex hull and LP based heuristics for the quadratic travelling salesman problem

*Rostislav Staněk, Peter Greistorfer, Klaus Ladner, Ulrich Pferschy*

The well-known travelling salesman problem (TSP) asks for a shortest tour through all vertices of a graph with respect to the costs of the edges. In contrast, the quadratic travelling salesman problem (QTSP) associates a cost value with every two edges traversed in succession. We consider a symmetric special case that arises in robotics, in which the quadratic costs correspond to the turning angles or to a linear combination of the turning angles and the Euclidean distances. We introduce two heuristic approaches, first one exploiting the geometric properties of a "good" tour and the latter one making use of auxiliary ILPs. If the quadratic costs correspond to the turning angles, optimal tours usually have the shape of large "circles" or "spirals". In each step of the first algorithm, a convex hull is built and its corresponding vertices are removed from the graph. This step is iteratively repeated leading to a set of nested subtours, which are subsequently patched into one single tour. Our second algorithm uses an LP relaxation and a rounding procedure to obtain a set of paths and isolated vertices. Afterwards, these paths are optimally patched into a single tour by means of a small auxiliary TSP instance, which is solved by an ILP-solver. Finally, the resulting tour is enlarged by adding the remaining isolated vertices using a cheapest insertion heuristic. Additionally, we present some further algorithmic enhancements to both approaches. Finally, all constructive results can be improved by running a classical 3-opt improvement heuristic. We provide exhaustive computational tests, which illustrate that both algorithms introduced significantly outperform the best-known heuristic approaches from the literature with a dominance of the LP based approach.

## 3 - Routing and order batching in a non-standard warehouse

*Ulrich Pferschy, Joachim Schauer*

We consider the warehouse logistics system of Blue Tomato, a sporting goods and apparel sales company with a strong e-commerce business. We focus on the order picking process in its central warehouse where every day articles for a few thousand orders are manually picked from the shelves. This is done by human pickers, who use a cart to store at most 15 different orders comprising a total of at most 40 articles. The resulting planning task consists of two parts: At first, the orders have to be partitioned into batches allowing an efficient picking tour in the warehouse. Secondly, for each batch a routing problem for the picker has to be solved, which can be modelled as an instance of a TSP on a special graph.

There are a number of non-standard aspects to consider: The warehouse consists of parallel aisles with two cross aisles and additional shelf space of irregular structure. Moreover, the warehouse consists of two floors which are connected by two elevators. For most products copies are stored in several different storage locations. Thus, the order batching process also has to decide from which location each product should be picked.

We develop a heuristic strategy for order batching which tries to build batches in a close spatial neighborhood. The definition of this neighborhood is based on a general graph model which allows a flexible adaptation to changes in the warehouse structure. The subsequent routing problem can be solved to optimality by a TSP algorithm. However, we also employ an insertion type heuristic with  $k$ -opt improvement, which deviates from the optimal TSP solution by less than 1% for the considered real-world instances. The resulting algorithmic framework yields a significant improvement on the total tour lengths of 34.4% on average.

## ■ FA-09

*Friday, 9:00-10:30 - WGS|108*

## Variants of the TSP (i)

Stream: Discrete and Integer Optimization

Parallel session

Chair: *Ulrich Pferschy*

## ■ FA-10

Friday, 9:00-10:30 - WGS|108a

### Large scale location and routing problems (i)

Stream: Discrete and Integer Optimization  
Parallel session

Chair: Bernard Fortz

#### 1 - Mixed-Integer Programming Model for the Joint Placement and Routing of Function Sequences

*Dimitri Papadimitriou*

In function-oriented networks, each node may execute concurrently a set of atomic functions such that demands which are described by source-destination pair, size and a finite sequence of ordered operations  $f_1, f_2, \dots, f_n$  can be satisfied when exiting the network. Note that the same operation may appear multiple times as part of the same sequence of operations. The problem consists of allocating the node processing and arc bandwidth resources such that set of commodities (service chains) can be handled at minimum cost by the deployed functions at each node. The goal is thus to jointly select the subset of nodes where to place operators and find a demand assignment (without exceeding both node processing and arc capacity) that minimizes the sum of location, supplying/running and transportation/routing costs. In this paper, we propose a mixed-integer programming formulation which combines a variant of the multi-product capacitated location (with precedence constraints to account for the operation order in the sequence) together with the fixed-charge multicommodity flow problem; thus, as a variant of the location-routing model. Next, in order to cope with demand variations over time (e.g., size and operation sequence), we extend our formulation to multiperiod problems. This so-called dynamic location-routing model aims at enabling adjustment of operators' placement and routing decisions at minimum reorganization cost, e.g., by limiting the number of changes in running demands. Note that accounting for operator relocation cost yields a quadratic formulation. Then, we propose computational methods and evaluate their performance over representative scenarios and compare the results with those obtained when solving both placement and routing problems independently.

#### 2 - A Benders decomposition approach for location of stations in an electric car sharing system

*Hatice Calik, Bernard Fortz*

The increasing number of privately owned cars pushes the city managers to find solutions to the increasing pollution, traffic congestion, and parking problems in urban areas. Electric car sharing systems, which are based on shared used of vehicles owned by a company or an organization, have a high potential of eliminating these problems by reducing car ownership if they are designed and operated in a way to provide high levels of accessibility and flexibility. In this study, we focus on design of a one-way car sharing system with a fleet of identical electric cars. The system under consideration provides flexibility in the sense that the users are allowed to leave the cars to stations different than their pick-up point and no pre-booking is enforced, which leads to uncertainty in demand. We approach the system from a strategic point of view and aim to decide on the location of stations and the initial number of cars available at each station in a way to maximize the expected profit. We introduce multiple demand scenarios to represent the demand uncertainty and formulate the problem as a mixed integer stochastic programming model. The profit function takes into account the expected revenue obtained from the user requests served and the fixed costs of opening stations and purchasing cars. We further develop a Benders decomposition method based on our formulation to solve this problem. In order to improve the convergence speed of our algorithm, we strengthen the master problem with valid inequalities, introduce a stabilization procedure, and propose primal heuristics to obtain good starting solutions. We conduct computational experiments on problem instances obtained from real data based on Manhattan taxi trips to evaluate the performance of our methods.

#### 3 - Using variables aggregation and Benders decomposition for solving large-scale extended formulations

*Bernard Fortz, Markus Leitner*

Many optimization problems involve simultaneous decisions on high-level strategic decisions such as the location and/or dimensioning of facilities or devices, as well as operational decisions on the usage of these

facilities. Moreover, these decisions often have to be taken for multiple demand sets over time or in an uncertain setting where multiple scenarios have to be considered. Hence, a large number of variables (and constraints) is often necessary to formulate the problem. Although sometimes more compact formulations exist, usually their linear relaxations provide much weaker lower bounds, or require the implementation of problem-specific cutting planes to be solved efficiently. A lot of research has focused in recent years on strong extended formulations of combinatorial optimization problems.

These large-scale models remain intractable today with traditional solvers, but Benders decomposition gained attention as successful applications of it have been reported. An alternative to these large-scale models is to use more compact formulations, often based on variable aggregations. We propose an intermediate strategy that consists of projecting the extended formulation on the space of aggregated variables with a Benders decomposition scheme, applicable to a large class of problems.

## ■ FA-11

Friday, 9:00-10:30 - WGS|005

### Stochastic Vehicle Routing

Stream: Logistics and Freight Transportation  
Parallel session

Chair: Alexandre Florio

#### 1 - A stochastic vehicle routing strategy for the collection of two similar products

*Epaminondas Kyriakidis, Theodosios Dimitrakos, Constantinos Karamatsoukis*

We develop and analyze a mathematical model for a specific stochastic vehicle routing problem in which a vehicle starts its route from a depot and visits  $N$  customers according to a particular sequence in order to collect from them two similar but not identical products. The actual quantity and the actual type of product that each customer possesses are revealed only when the vehicle arrives at the customer's site. It is assumed that the vehicle has two compartments. We name these compartments, compartment 1 and compartment 2. It is assumed that compartment 1 is suitable for loading product 1 and compartment 2 is suitable for loading product 2. However it is permitted to load items of product 1 into compartment 2 and items of product 2 into compartment 1. These actions cause extra costs that are due to extra labor. The vehicle is allowed during its route to return to the depot to unload the items of both products. The travel costs between consecutive customers and the travel costs between the customers and the depot are known. The objective is to find the routing strategy that minimizes the total expected cost among all possible strategies for servicing all customers. It is possible to find the optimal routing strategy by implementing a suitable stochastic dynamic programming algorithm.

#### 2 - An Approximate Dynamic Programming Based Heuristic for Stochastic Time-Dependent Vehicle Routing Problems

*Mustafa Çimen, Mehmet Soysal, Cagri Sel, Sedat Belbag*

This paper addresses a Time Dependent Vehicle Routing Problem with stochastic vehicle speeds. A Markovian Decision Process approach has been used to formulate the problem. The model respects time-dependent and stochastic vehicle speeds while calculating routing costs comprising fuel and wage costs. The Time Dependent Capacitated Vehicle Routing Problem is known to be NP-Hard for even deterministic settings. The problem accounting for stochastic vehicle speeds further increases complexity which renders classical optimization methods infeasible. We propose an Approximate Dynamic Programming based heuristic approach for solving the problem. Computational analyses on several instances show the added value of the proposed decision support tool. The results show that incorporating vehicle speed stochasticity into decision support models has potential to improve the performance of resulting routes in terms of travel duration, emissions and travel cost. In addition, the proposed heuristic provides promising results within relatively short computation times.

#### 3 - The Stochastic Delivery Problem: Optimizing the Number of Successful Deliveries of Courier Companies

*Alexandre Florio, Dominique Feillet, Richard Hartl*

In this talk we introduce the Stochastic Delivery Problem (SDP), an optimization problem relevant to the parcel delivery market. In the SDP, the objective is to maximize the number of successful deliveries to customers. This objective goes hand in hand with customer satisfaction, and also contributes to the reduction of costs related to unsuccessful delivery attempts.

In order to propose a realistic description of the problem, we present the concept of a customer availability profile, which to some extent can be considered as a generalization of the time window notion. The availability profiles are essentially functions mapping the entire delivery period into the unit interval, and denote the likelihood of a customer being available for receiving a delivery at a particular moment.

We propose an exact branch-and-price algorithm for solving the SDP. After applying Dantzig-Wolfe decomposition, the resulting pricing problem resembles an orienteering problem (OP) with time-dependent rewards, which we solve with a labeling algorithm. Different from other applications of the framework to routing problems, in our case efficient and strong label dominance rules cannot be derived. Nevertheless, by applying the idea of reduced cost bounding we are able to avoid combinatorial explosion and solve exactly the pricing problem. We adapt bounds from the literature, and we also propose a new bound for the OP. Computational experiments show the effectiveness of the method to solve SDP instances of up to 75 customers.

## ■ FA-13

Friday, 9:00-10:30 - RVH|I

### Smart City and Environment

Stream: Business Analytics, Artificial Intelligence and Forecasting

Parallel session

Chair: Julian Bruns

#### 1 - Detecting Changes in Statistics of Road Accidents to Enhance Road Safety

Katherina Meißner, Cornelius Rüther, Klaus Ambrosi

When trying to detect changes in car accident statistics, police analysts are faced with a large amount of incidents on the one hand and about 70 attributes with several attribute values leading to multitudinous possible combinations on the other. Of course, not all combinations and changes therein are essential to decide upon police actions to enhance road safety. But defining potentially interesting combinations to track in advance can lead to a narrow perspective on the actual situation. If there was an increase in the frequency of a particular combination, which had not manually been predefined, this increase would remain unrecognized and therefore untreated by the police for some periods.

Tracking changes manually in these numerous operating figures is not possible. Hence, we propose an automated approach based on Frequent Itemset Mining using known algorithms, such as Eclat or Apriori, to detect significant changes in these figures. Firstly, the 1.8 million records of Great Britain's road safety data openly published by the Department for Transport are prepared and adjusted to match the algorithms' requirements. Secondly, the most frequent itemsets for each time interval are filed and compared to the itemsets of the previous period and are split into classes of changing, stable and semi-stable itemsets.

To generate our framework we concentrate on the support of frequent itemsets and the changes between the months of two consecutive years. One major question to be answered within our framework is how to find changing itemsets that are worth being presented to the police analyst.

#### 2 - New technologies, which are the main role in the formation of information society, are computer and communication-communication technologies

Huseyin Demir

People's expectation to live in a more contemporary environment has also brought about rapid development in technology. Throughout this development, undertaking the role of training locomotive, which is briefly defined as culturing and culturing process. At the same time, the technological development that can be considered as a product of the education process also changed the structure of the education process and brought a different perspective to the understanding of education.

Despite the fact that technology has not been developed mainly for educational purposes within the process of technological development that has developed from day-to-day, this understanding has gradually begun to change. How do we teach basically? Especially the media dimension of the discipline of Education Technology which seeks an answer to the question has become more contemporary and its borders have been getting larger. The development of the qualities of the individual-knowledge-society trio has brought about the development of the contemporary social structure and the functioning of this structure, as well as the change in the qualities of the individual, the function of information in the individual and society life.

#### 3 - Predicting habitable zones of invasive species based on temperature

Julian Bruns, Daniel Seebacher, Manuel Stein

Invasive species can have a negative impact on human health, agriculture as well as the ecological balance of an ecosystem. A well-known example is the Asian tiger mosquito. Detecting such species early in their ontogenesis is vital for minimizing their spread and dealing with them effectively. In particular, the temperature is one of the most relevant factors in detecting potential breeding grounds and habitats. These species can often only live and breed in certain temperature intervals. Unfortunately, temperature in-situ measurements are scarce and expensive while remote measurements have a trade-off between low spatial or low temporal resolution as well as inherent uncertainty component. In this work, we propose a joint model which predicts fine grained (spatio-temporally) temperature intervals on the surface based on remote sensors together with the underlying surface characteristics. To model the inherent uncertainty of the data sources as well as forecast, a Bayesian hierarchical modelling approach is employed. We use the *Drosophila sukuzii* for the used temperature interval, as this species only breeds between 10°C and 30°C and is highly damaging to crops such as wine grapes. The focus of this study is the area of south-west Germany, where the species was already detected in the past. The detection of suitable habitats and breeding grounds of this invasive species may lead to future prediction of its expansion paths and possible counter strategies. To efficiently convey the location of possible habitats and breeding grounds, we make use of current state-of-the-art geospatial visualization techniques. The uncertainty inherent in the Bayesian hierarchical modelling approach is, additionally, displayed to increase the users trust in the analysis process.

## ■ FA-14

Friday, 9:00-10:30 - RVH|II

### Revenue Management in Transport and Logistics

Stream: Pricing and Revenue Management

Parallel session

Chair: Arne Karsten Strauss

#### 1 - Simulation-based Learning for Dynamic Time Window Allocation in Attended Home Deliveries

Magdalena Lang, Catherine Cleophas, Jan Fabian Ehmke

For attended home delivery services, allocating time windows to delivery requests affects both delivery costs and the future orders that can be accepted given a limited delivery capacity. Revenue management provides approaches to forecast the demand for deliveries per time window and to efficiently control the time window allocation, but it requires to know an order's capacity consumption and the resulting left-over capacity. For deliveries, the travel time needed to service an order depends on the overall set of accepted orders, so that the effect on capacity cannot be finally determined on individual order request arrival. Vehicle routing methods can approximate travel time and costs, but lack sufficient means to anticipate stochastic customer choice and to effectively deploy allocation controls. Moreover, vehicle routing is usually too time-consuming to be computed per arriving order request. Here, we present a simulation-based learning framework to approximate the opportunity costs of time window allocation. These opportunity costs can then inform a dynamic allocation decision on request arrival. Thereby, the approach anticipates effects on both overall acceptable revenue from orders and delivery costs. It uses simulated request arrival samples to estimate the future effects of control decisions. We present first results of a computational study.

## 2 - Profit-Maximizing Time Window Selection Under Consideration of Customer Choice in Attended Home Delivery

*Claudius Steinhardt, Jochen Mackert, Robert Klein*

The interface between revenue management (RM) and vehicle routing (VR) is investigated with increasing attention by a steadily growing research community. Thin profit margins, high service requirements, and the challenge of ensuring efficient operations when delivering to the front door of a customer (known as "last mile delivery") in home delivery service models motivates the application of RM techniques in order to manage demand. In the literature, four general demand management concepts have been identified to be adequate for delivery service models: While Differentiated Slotting and Differentiated Pricing focus on decisions on a tactical level, Dynamic Slotting and Dynamic Pricing have been proposed to enhance operational decisions. Besides giving an overview of the latest research in the field of Attended Home Delivery, this talk especially focuses on a model-based decision support for demand management via Differentiated Slotting. The proposed mixed integer program aims at deciding about how many and which delivery time windows should be on offer for customers in each delivery area of the e-grocer in order to maximize expected total profits. It explicitly incorporates customer choice behavior, allowing the e-grocer to split the market in different customer segments. Linearization techniques are applied to facilitate the application of standard software packages to solve the model.

## 3 - Realtime pricing in B2B truck logistics

*Alwin Haensel*

Automated pricing is delicate when it comes to dynamic market prices, especially when prices are mainly based human negotiations. We have developed a pricing algorithm for the logistics platform Cargonexx ([www.cargonexx.de/en/](http://www.cargonexx.de/en/)), which is used to derive the current market price for each individual transport request. Cargonexx is an intermediary between the contractors and the freight carriers. The proposed price must reflect the current market situation on both market sides as precisely as possible. To solve this stochastic problem, we use fuzzyfication of observations and machine learning techniques to build probability distributions for the price acceptance. In the talk, we will focus on the challenges and solution approaches.

## ■ FA-15

*Friday, 9:00-10:30 - RVH|III*

### Modern Methods for Microsimulations

Stream: Simulation and Statistical Modelling

*Parallel session*

Chair: *Ralf Münnich*

#### 1 - Mikrosimulation im Wandel der verfügbaren Daten

*Markus Zwick*

Die Verwendung von Verfahren der Mikrosimulation(Ms)zur Abschätzungen von Politikmaßnahmen hat in Deutschland eine gewisse Tradition. Zur Ms gehören neben der Methodik vor allem aber auch ausreichende Einzeldatenbestände und diese am besten im Querschnitt wie über die Zeit zusammengeführt. Die Projekte ‚Sozialpolitisches Entscheidungs- und Indikatorensystem für die Bundesrepublik Deutschland‘ und in der Folge der Sfb 3 der DFG ‚Mikroanalytische Grundlagen der Gesellschaftspolitik‘ haben schon früh einen Bedarf an Einzeldaten artikuliert und für die wissenschaftliche Forschung gefordert, dies hat die Verfügbarkeit von Mikrodaten nachhaltig verändert. Mit dem Konzept der faktischen Anonymität und später mit den Forschungsdatenzentren sind heute nahezu alle amtlichen Einzeldaten für die Forschung erschlossen. Was bis heute in weiten Teilen fehlt ist die Akzeptanz und für Deutschland auch die rechtliche Grundlage, verschiedene Mikrodatenbestände für Analysen und Simulationen zusammenzuführen. Es stehen zwar prinzipiell viele Einzeldaten für die Forschung zur Verfügung aber häufig nur mit begrenztem Berichtkreis und mit einem eher schmalen Umfang an Merkmalen. Datenintegration ist hier die Antwort und dies nicht nur für die Wissenschaft sondern insbesondere auch für die amtliche Statistik. Künftig werden wesentlich häufiger Datenprodukte in die Analysen und Simulationen eingehen, die aus Befragungs-, administrativen und neuen digitalen Daten (Big Data) bestehen. Der Vortrag wird die Entwicklung der Ms anhand der Zugänglichkeit von Mikrodaten darstellen. Der Focus liegt

dabei auch auf den Möglichkeiten neue digitale Daten mit klassischen Mikrodaten zu verbinden und so vollständig neue Wege in der Simulation zu beschreiben.

#### 2 - Sensitivity Analysis for Demography Based Microsimulation

*Jan Pablo Burgard, Simon Schmaus*

With the incorporation of microsimulations into the Federal Statistics Act - BStatG in Germany the Bundestag encourages the use of microsimulation in political decision processes. In many areas of political decision making, e.g. in transport infrastructure, microsimulation has been a strongly applied methodology. Usually such microsimulation make use of agents or representatives to incorporate differing behavior between individuals. With nowadays computer power, also demography based microsimulations come into perspective. Instead of using a subset of the population or just a few agents, with demographic based microsimulations the change is measured for a total population and for each unit within. This enables the modeling of much finer and more diverse behavioral attitudes. Further, as the base population is constructed for a multipurpose framework, many variables are available in a coherent manner easing the extension to new microsimulation tasks.

The different transition processes in the population such as births and deaths, relocations, and change in household characteristics are organized in modules, as there exist often multiple opinions on their modeling. These modules and their ordering have an impact themselves on the outcome of the microsimulation. We propose to assess the outcome of a demography based discrete-time stochastic microsimulation using the concept of sensitivity analysis which is well established for indicator assessment in survey statistics. With this concept we can visualize the main effects of the models and their parameters, the modules, and the assumptions made on a microsimulation task. It enables the detection of the influence of single parts and possibly harmful settings.

#### 3 - A network-flow approach to address selection for populations

*Ulf Friedrich*

Several algorithmic challenges have to be solved for microsimulations in the context of survey statistics. These often involve mathematical optimization problems and typically integrality constraints on some or all optimization variables, e.g., to model the simulated members of a population or to describe (binary) decisions within the model. It is therefore necessary to employ combinatorial optimization techniques to many microsimulation problems.

In this work, the address selection problem in microsimulations is studied. After a population of a given region has been generated in the first step of the microsimulation process, the members of the population have to be assigned to actual addresses in a given region. In doing so, the pure address selection problem (i.e., the decision for addresses to consider in the simulation) is extended by additional distribution constraints and structural properties of the households. These constraints lead to a hard generalization of the classical matching problem and make the problem computationally challenging. A network-flow formulation for the selection problem is presented and compared to similar combinatorial optimization problems. Based on this analysis, solution algorithms are proposed and tested on a real-world data set.

## ■ FA-17

*Friday, 9:00-10:30 - RBM|2204*

### Scheduling and Staffing 1

Stream: Project Management and Scheduling

*Parallel session*

Chair: *Thomas Kesselheim*

#### 1 - A Large Neighbourhood Search approach for the Nurse Rostering Problem

*Joe Bunton, Andreas Ernst, Mohan Krishnamoorthy*

Nurse rostering problems involve assigning nurses to shifts, subject to various hard and soft constraints due to work/enterprise regulations and personal work preferences of the nurses. The objective is to satisfy as many of the workforce/cover requirements and soft constraints as possible, subject to satisfying the desired hard constraints. Due to the difficulty of many nurse rostering problems, finding good quality solutions often requires the application of sophisticated heuristic algorithms. Large neighbourhood search based heuristic methods have been shown to be effective in solving difficult problems in areas such as



transportation and scheduling. In this paper, we present a large neighbourhood search heuristic for the nurse rostering problem. By formulating the nurse rostering problem using a work-stretch approach, we are able to solve reasonably large-sized problems quickly, as long they only involve a small number of shift types. This large neighbourhood search method exploits our ability to solve certain subsets of the larger problems quickly using mixed integer programming, allowing local improvements on a large neighbourhood of the current solution while maintaining feasibility. We investigate several improvements to such a scheme for the nurse rostering problem. We also test our approach on standard datasets from the literature to show the effectiveness of our approach.

## 2 - Job scheduling with simultaneous assignment of machines and multi-skilled workers: a mathematical model

*Cinna Seifi, Jürgen Zimmermann*

The primary task of mining companies is the extraction of mineral raw materials. Based on a planning program, a certain quantity of raw materials is expected to be extracted within a given time horizon. The room-and-pillar mining method using the drilling and blasting technique is characterized by nine process steps each of which has to be executed by some appreciated machine and worker and is associated with a certain amount of raw material. Derived from superordinate planning level as well as a constant comparison of planned and actual data of the excavated raw material, the quantity of material that must be achieved is predetermined for each process step within a work shift. The processing time of a process step (job) depends on the assigned devices and workforces, in particular, on the skill levels of the workforces for the device. In this paper, we formulate a mathematical program for a simultaneous assignment of devices and personnel to a selection of jobs. The aim is to minimize the difference between the predetermined quantity and the amount of extracted raw material, cumulatively over all the process steps, for a work shift. Preliminary results achieved with Xpress shows that our model is suitable for practical problem instances.

## 3 - The Temp Secretary Problem and Partly-Stochastic Models for Online Scheduling

*Thomas Kesselheim, Andreas Tönnis*

The Temp Secretary Problem was recently introduced by Fiat et al. [ESA 2015]. It is a generalization of the Secretary Problem, in which commitments are temporary for a fixed duration. This way, the Temp Secretary Problem nicely introduces beyond-worst-case analyses to online scheduling problems.

We present a simple online algorithm with improved performance guarantees for cases already considered by Fiat et al. and give competitive ratios for new generalizations of the problem, such as for example different durations. Our algorithmic approach is a relaxation that aggregates all temporal constraints into a non-temporal constraint. Then we apply a linear scaling algorithm that, on every arrival, computes a tentative solution on the input that is known up to this point. This tentative solution uses the non-temporal, relaxed constraints scaled down linearly by the amount of time that has already passed.

## ■ FA-18

*Friday, 9:00-10:30 - RBM|2215*

### Cranes and Robots

Stream: Project Management and Scheduling  
*Parallel session*

Chair: *Jenny Nossack*

#### 1 - Assignment, Scheduling and Routing of Triple-Crossover-Cranes in Container Yards

*Lennart Zey, Dirk Briskorn*

In recent years the need for efficient processes in sea ports has grown due to the increasing volume of maritime transport. With the help of Automated Stacking Cranes (ASCs) which store and relocate containers in container blocks the corresponding storage processes can be improved significantly concerning time and productivity. The triple-crossover-crane setting, with one large crane that can cross two small

cranes of equal height and width, is a setup that promises high productivity in container handling. Nonetheless, with a growing number of cranes working jointly in a storage block, interference between cranes likely increases. Thus, the full potential of the crane setting can only be achieved when taking into account conflicts between cranes in a planning procedure. Aiming at minimal makespan, we develop a branch-and-bound approach that assigns container-jobs to cranes, determines fulfillment sequences and routes the cranes such that the resulting schedules are conflict free. In this talk we present both, an exact as well as a heuristic variant and compare the numerical results.

#### 2 - Optimizing Periodic Schedules in Robot Based Manufacturing Lines

*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. Furthermore, the progress shall proceed – production cannot be too fast, too safe or too cheap.

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.

The talk will be about the periodic event scheduling problem proposed by Serafini and Ukovich in 1989 as well as its cycle periodicity formulation. In order to obtain a suitable formulation with a small number of integer offset variables it plays a crucial role to choose an appropriate cycle basis of the underlying precedence graph. Our actual research focuses on the latter aspect. We identified appropriate cycle bases as well as admissible bounds for the remaining integer offset variables.

#### 3 - Preventing Crane Interferences at Automated Container Terminals

*Jenny Nossack, Dirk Briskorn, Erwin Pesch*

We focus on a container dispatching and conflict-free yard crane routing problem that arises at a storage yard in an automated, maritime container terminal. A storage yard serves as an intermediate buffer for import/export containers and exchanges containers between water- and landside of a maritime terminal. The considered storage yard is perpendicular to the waterside and employs two rail mounted gantry cranes that have different sizes and have thus the possibility to cross each other. The problem at hand evaluates in which order and by which crane the import/export containers are transported in order to minimize the makespan and prevent crane interferences. We solve this problem to optimality by a branch-and-cut approach that decomposes the problem into two problem classes and connects them via logic-based Bender cuts. Furthermore, we propose a heuristic approach and assess the quality of our solution methods in a computational study.

## ■ FA-19

*Friday, 9:00-10:30 - RBM|3302*

### Production and Maintenance Planning

Stream: Production and Operations Management  
*Parallel session*

Chair: *Sandra Transchel*

#### 1 - Maintenance Planning Using Condition Monitoring Data

*Daniel Olivotti, Jens Passlick, Sonja Dreyer, Benedikt Lebek, Michael H. Breitner*

Maintenance activities of machines in the manufacturing industry are essential to keep machine availability as high as possible. Especially in large production sites with a high number of interlinked machines, the fulfillment of maintenance specifications is a major challenge. A breakdown of a single machine can lead to a complete production stop. Maintenance is traditionally performed by predefined maintenance specifications of the machine manufactures. With the help of condition-based maintenance, maintenance intervals can be optimized

due to detailed knowledge of the machine condition through sensor data. This results in an adapted maintenance schedule where machines are only maintained when necessary. Apart from time savings, this also reduces costs.

A high production utilization is a major goal in the manufacturing industry. It is necessary to link the maintenance activities to the production program to make machines available when they are needed the most. An optimization model for maintenance planning is developed considering the right balance between the production program, the failure probabilities of the machines and potential breakdown costs. The current conditions of the machines are used to forecast the necessary maintenance activities for several periods. A decision support system helps maintenance planners to choose their decision-making horizon flexibly. It can be decided individually how often the maintenance schedule is optimized anew. This flexibility underlines a main goal of the optimization model, the applicability in practice.

## 2 - Production Planning and Quality Testing Under Random Yield with Two-Dimensional Quality

*Sandra Transchel, Candace Yano*

We consider a firm operating a co-production system over multiple periods. Finished products are differentiated according to their quality levels, specified in two dimensions. The firm faces uncertain demands for these quality-differentiated products that are sold at different prices, and can fulfill demand using substitute products of equal or higher quality. Our motivating example comes from the semiconductor industry; the two quality dimensions are processor speed and heat resistance. Every week the firm decides the number of wafers to order (each of which contains hundreds to thousands of "chips"), which will arrive about 10 weeks later. Upon arrival, an initial (quick) test is performed on each chip, which is then classified into one of several quality "bins." At this point, all chips with an acceptable quality level are converted into so-called packaged devices. A more time-consuming test is required to determine the exact quality category; the final quality may be higher or lower than the initial quality. Every week, the firm must also decide how many packaged devices from each initial-quality bin should be tested and for which quality specifications each should be tested. The time required for a test generally increases in the quality level for which the device is being tested and the testing capacity is limited. In addition, the firm must allocate post-final-test chips to satisfy demand, recognizing the opportunity cost of fulfilling demand for low-quality products using higher-quality products. The firm seeks to maximize expected profit. We develop a stochastic dynamic programming model with three types of decisions: (i) the wafer ordering decisions, (ii) the testing policy for the chips, and (iii) the allocation of the post-final-test inventory to demand.

## 3 - Optimization of Work-Center Cycle Time Target Setting in a Semiconductor Wafer Fab

*Hermann Gold, Hannah Dusch*

We consider a semiconductor fab which has been given realistic overall cycle time targets by product for the whole manufacturing network but where the task remains to break these overall targets down to individual process steps and work centers, in a way which is realistic, efficient and fair. Our method proposed has the additional advantage that it reduces the fab logistics complexity significantly.

At first we introduce a queueing network perspective to the target setting procedure. Today's procedure attaches lower normalized waiting time targets to longer jobs, according to a function which is reciprocal to the square root of the physical cycle time. We analyze and discuss the truths and myths of this procedure.

Secondly, we introduce a Kelly queueing network approximative model of our manufacturing system based on the resource pooling principle which application to semiconductor manufacturing has been explained in earlier work by H.Gold. We apply M/G/1-conservation laws together with linear and quadratic programming approaches to the problem of adjusting unified normalized waiting times at resource pool level in a way that overall target cycle times are not violated. It turns out, that our LP approach is more fair, but less efficient than the QP approach, due to the fact, that in the LP approach overall cycle time targets are overreached for a variety of products. With our QP approach overall fab cycle time targets are met exactly.

In the third step we drop the connection to the existing target setting system and establish unified normalized waiting times at the resource pool level merely upon Kelly network analysis. Hereby a new idea to capture the degree of freedom is applied, namely the concept of Shannon entropy from information theory.

## ■ FA-20

Friday, 9:00-10:30 - RBM|4403

## Supply Chain Contracts and Finance

Stream: Supply Chain Management

Parallel session

Chair: *Gerd J. Hahn*

### 1 - Analysis of a Revenue Sharing Contract in a Reverse Supply Chain

*Ismail Serdar Bakal, Majid Biazaran*

Many Original Equipment Manufacturers that engage in the remanufacturing business fully or partially outsource take back activities. Although outsourcing reverse activities seems to be a reasonable option, it may result in significant inefficiencies due to decentralization. Several contracting mechanisms have been proposed to reduce the inefficiencies in the forward chains. However, the effectiveness of these contracts has not been fully investigated in reverse chains. In this study, we investigate a two-echelon reverse supply chain, consisting of a remanufacturer and a collector in a single-period setting. The collector is in charge of acquiring used products from end customers by paying an acquisition price per unit of used products. The collected products are then sold to the remanufacturer who faces a random demand for remanufactured products. We first consider the centralized setting and derive the optimal acquisition price. Then, we study the decentralized setting under remanufacturer's lead and collector's lead. In both cases, we demonstrate that as long as the total cost of reverse activities are constant, the channel performance is independent of how these costs are distributed among the parties. Next, we focus on coordination issues and show that there exists a menu of revenue sharing contracts that can coordinate the reverse supply chain and allows for arbitrary allocation of total channel profit between the parties.

### 2 - When to Offer Upgrades?

*Rowan Wang*

In this paper, we build a capacity and revenue management model from a consulting project. We consider a firm that sells multiple product models corresponding to multiple classes of demand (customers). Each class of customers requests for one particular product model, and the firm can offer customers free upgrades to more expensive models when there is insufficient stock of the preferred ones. However, customers may not accept the upgrades due to their preferences on their desired models. Customers arrive over time. The firm needs to decide whether or not to offer upgrades upon the arrival of each individual customer. We formulate the problem using a Markov decision process model and prove that the optimal profit function is anti-multimodular. Based on this property, we prove that the structure of the optimal upgrade policy can be described by dynamic thresholds that depend on the inventory levels of all products. Importantly, we show that, with the possibility that customers would reject upgrades, it is optimal to offer upgrades before the stockout of the desired models. Offering upgrades only after stockout could lead to significant profit loss.

### 3 - A Financial Market Perspective on Value Chain Performance

*Gerd J. Hahn, Jochen Becker, Marcus Brandenburg*

Approaches to financial performance management in value chains typically involve a top-level financial performance measure and value driver analysis to quantify relevant operational performance levers. Internal, accounting-based measures such as EVA, ROCE or DCF are frequently used for this purpose. In contrast, we analyze value chain performance from a financial market perspective to shed light on the question whether and to what extent value driver analysis actually creates value and is appreciated by the stock markets. For this purpose, we apply data envelopment analysis to a large longitudinal data set of listed US companies. Our study covers a diverse set of more than ten industries and investigates value chain competitiveness both within and across industries.

## ■ FA-21

Friday, 9:00-10:30 - RBM|4404

### Engineering Applications of OR Techniques

Stream: OR in Engineering

Parallel session

Chair: Armin Fügenschuh

#### 1 - Optimization of non-ideal Multi-component Distillation Processes using Kriging Interpolation

Dennis Michaels, Tobias Keßler, Achim Kienle, Christian Kunde, Nick Mertens

Separation processes based on distillation play an important role in chemical industry. Hence, the determination of cost-minimal designs for such processes is of particular interest. This task can often be modeled as a mixed-integer nonlinear optimization problem (MINLP) that needs to be solved globally. Due to the high complexity, global optimization of these problems is in general very challenging. In this talk, ideal and non-ideal multi-component distillation column processes are considered. In order to reduce the computational complexity of the corresponding MINLPs, the column models are approximated with the help of an iterative Kriging interpolation. The approximated models are solved to global optimality, and the results are compared with results obtained by rigorous optimization of the original distillation column. Numerical examples are considered, showing the usefulness of the Kriging approach from a practical point of view.

#### 2 - The Multistatic Sonar Location Problem and Mixed-Integer Programming

Armin Fügenschuh, Emily Craparo

Sonar is a technique to detect objects that are underwater or at the surface using sound propagation. In active sonar systems, a sound is emitted from a source and its echoes are detected by a receiver, revealing information about nearby objects. In monostatic systems, the source and the receiver are located in the same place. Bistatic sonar uses a source and a receiver in different locations. Multistatic sonar uses several sources and receivers simultaneously. For the surveillance of a large area of the ocean, a number of both types of devices must be deployed. Since the sources are much more expensive than the receivers, one may wish to field a sparse network of receivers and then ensnare the area with a powerful source, such as a large source attached to a helicopter and dipped in the ocean. Alternatively, one may use a network of many sources and receivers, all of which are attached to sonobuoys. In this case, the optimization problem is to find a network design that is able to cover all of a desired area. The detection probability of a target from a single pulse between source and receiver is constant in a nonconvex region due to propagation losses and dead zones. The goal is to raise the detection probability above a desired level, if necessary by combining results from different source-receiver pairs. We present a mixed-integer nonlinear formulation for the multistatic sonar source-receiver location problem and discuss several linearizations. We compare these formulations empirically using topological data from coastline areas around the world and a state-of-the-art solver MIP solver.

#### 3 - A Stochastic Optimization Model for Energy Management of Storage-Augmented Hybrid Multi-Building Districts Considering Battery Aging Costs

Timm Weitzel, Maximilian Schneider, Christoph Glock, Stephan Rinderknecht

The share of energy generated decentrally from renewable energy sources in the total amount of energy generated has increased over recent years, and it is expected to increase further in the years to come. To overcome the challenges associated with integrating different heterogeneous energy resources and with securing efficient operations, intelligent microgrids will likely become more important in the future. An application for intelligent microgrids are multi-building districts with local thermal and electrical energy production. Operating such systems is challenging for two reasons. Firstly, thermal and electrical energy demand do not occur simultaneously requiring storages for an efficient operation of coproduction units such as combined heat and power plants. Secondly, renewable production is unsteady and uncertain and does not necessarily follow demand. The work at hand investigates a multi-building district equipped with a Battery Energy Storage System (BESS) and a Thermal Energy Storage System (TESS) that participates in energy markets. The system faces uncertainty from

renewable production and market prices. This work contributes to research by formulating a stochastic optimization model for the Energy Management System (EMS) considering non-linear battery-aging costs and detailed cogeneration models. Since BESS deteriorate depending on usage and surrounding conditions, battery-aging costs are included into the optimization model to ensure feasible and economically viable operations. The optimization model is formulated as a stochastic MILP and solved using commercially available solvers. Computational studies are performed to illustrate the merits of the stochastic optimization and the interdependencies that arise between the operation of TESS and BESS.

## ■ FA-22

Friday, 9:00-10:30 - HFB|A

### MCDM 6: Software and Implementation

Stream: Decision Theory and Multiple Criteria Decision Making

Parallel session

Chair: Martin Josef Geiger

#### 1 - Integrating process mining and PROMETHEE for enhancing decision making in healthcare

Sudhanshu Singh, Rakesh Verma

Organizations working in the areas of healthcare while required to work in very dynamic and complex situations also have to apply multi-disciplinary methods which are driven by the contextual requirements. It is not uncommon to see a good amount of activities being performed in an ad hoc manner, driven by personal experience in the absence of an data based analysis. We cannot ignore data as it tells us about reality as it has happened or happening. Process mining is a research discipline that lies between one end of computational intelligence and data mining and the other end of process modelling and analysis. Data from event logs is utilized by process mining to discover processes, compliance and replay on existing process. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), is an outranking approach under the broader area of multi criteria decision making. In any journey towards improvement, we are required to make decisions which are driven by facts(data) and opinions(expert). Both process mining and PROMETHEE have seen applications in different areas including healthcare. In this paper we propose an approach that utilizes both of them whereas we utilize process mining to provide details of the process flows and bottlenecks and subject the results to PROMETHEE in making decisions. By adopting this approach, any healthcare organisation can bring in more clarity and enable decision makers to become more realistic on the existing state of an organization.

#### 2 - PolySCIP - Solving Multi-criteria Integer Programs

Sebastian Schenker

PolySCIP is a new solver for multi-criteria integer and multi-criteria linear programs. It is available as an official part of the non-commercial constraint integer programming framework SCIP. The new version of PolySCIP uses a novel partitioning approach for computing the entire set of non-dominated points for multi-criteria integer programs. The first partition contains non-dominated points whose corresponding efficient solutions are also efficient for a restricted subproblem with one less objective; the second partition comprises the non-dominated points whose corresponding efficient solutions are inefficient for each of the restricted subproblems. This algorithmic approach has the property that the first partition yields upper bounds as well as lower bounds on the objective values of potential non-dominated points in the second partition. Thus, in addition to computing the entire set of non-dominated points, we can restrict the computation to the first partition which yields an approximation on the entire set of non-dominated points.

#### 3 - Solving large-scale, mid-term planning problems under multiple objectives - A contribution to VeRoLog 2017 optimization competition

Martin Josef Geiger

The talk presents a solution approach for the recent implementation challenge of the EURO Working Group on Vehicle Routing and Logistics Optimization, a multi-objective, multi-period vehicle routing problem with pickups and deliveries. Important objectives comprise the classical minimization of the length of the routes, but also other considerations such as the fleet size, as well as the product levels over

a longer planning horizon. Between the objectives, considerable trade-offs exist that result in a true multi-criteria view on the problem at hand (although the objectives are, for the purpose of the challenge, combined in an overall cost function). Reflecting the different scenarios and data sets, a general solution framework has been developed that first allows the setting of the relative importance of criteria. Then, the data set is solved by means of several techniques: (i) Variable Neighborhood Search is used for the routing of the vehicles; (ii) lower bounds have been found and computed for the product levels: they guide the search towards qualitatively good solutions. As the VeRoLog Solver Challenge is, at this date, still on-going, we cannot conclude on the definitive quality of our contribution. At the moment, i.e., May 8, 2017, we have the best known solutions to 23 of the 25 benchmark instances, which is satisfactory. Independent from the final outcome, and based on a large number of experiments, we are certainly able to show that our approach is able to address a range of structurally different data sets and scenarios.

## ■ FA-23

Friday, 9:00-10:30 - HFB|B

### Network Optimization under Competition (i)

Stream: Game Theory and Experimental Economics  
*Parallel session*

Chair: Tobias Harks

#### 1 - Strategic Contention Resolution with Limited Feedback

Martin Gairing

We study contention resolution protocols from a game-theoretic perspective. We focus on acknowledgment-based protocols, where a user gets feedback from the channel only when she attempts transmission. In this case she will learn whether her transmission was successful or not. Users that do not transmit will not receive any feedback. We are interested in equilibrium protocols, where no player has an incentive to deviate. The limited feedback makes the design of equilibrium protocols a hard task as best response policies usually have to be modeled as Partially Observable Markov Decision Processes, which are hard to analyze. Nevertheless, we show how to circumvent this for the case of two players and present an equilibrium protocol. For many players, we give impossibility results for a large class of acknowledgment-based protocols, namely age-based and backoff protocols with finite expected finishing time. Finally, we provide an age-based equilibrium protocol, which has infinite expected finishing time, but every player finishes in linear time with high probability.

Joint work with: Georgios Christodoulou, Sotiris Nikolettseas, Christoforos Raptopoulos, and Paul Spirakis

#### 2 - A Characterization of Undirected Graphs Admitting Optimal Cost Shares

Anja Huber, Tobias Harks, Manuel Surek

In a seminal paper, Chen, Roughgarden and Valiant [Designing network protocols for good equilibria. *SIAM Journal on Comp.*, 2010] studied cost sharing protocols for network design with the objective to implement a low-cost Steiner forest as a Nash equilibrium of an induced cost-sharing game. One of the most intriguing open problems up to date is to understand the power of budget-balanced and separable cost sharing protocols in order to induce low-cost Steiner forests. In this work, we focus on undirected networks and analyze topological properties of the underlying graph so that an optimal Steiner forest can be implemented as a Nash equilibrium (by some separable cost sharing protocol) independent of the edge costs. We term a graph efficient if the above stated property holds. As our main result, we give a complete characterization of efficient undirected graphs for two-player network design games: an undirected graph is efficient if and only if it does not contain at least one out of few forbidden subgraphs. Our characterization implies that several graph classes are efficient: generalized series-parallel graphs, fan and wheel graphs and graphs with small cycles.

#### 3 - Equilibrium Computation in Atomic Splittable Singleton Congestion Games

Veerle Timmermans, Tobias Harks

We devise the first polynomial time algorithm computing a pure Nash equilibrium for atomic splittable congestion games with singleton strategies and player-specific affine cost functions. Our algorithm is purely combinatorial and computes the exact equilibrium assuming rational input. The idea is to compute a pure Nash equilibrium for an associated integrally-splittable singleton congestion game in which the players can only split their demands in integral multiples of a common packet size. While integral games have been considered in the literature before, no polynomial time algorithm computing an equilibrium was known. Also for this class, we devise the first polynomial time algorithm and use it as a building block for our main algorithm.

## ■ FA-24

Friday, 9:00-10:30 - HFB|C

### Optimal Control and Applications

Stream: Control Theory and Continuous Optimization  
*Parallel session*

Chair: Andrea Seidl

#### 1 - Optimal Control of 'Deviant' Behavior

Gustav Feichtinger

For several decades, Pontryagin's maximum principle has been applied to solve optimal control problems in engineering, economics, or management. Early Operations Research applications of optimal control include problems such as production planning, inventory control, maintenance, marketing, or pollution control. Since the mid-nineties, optimal control models of illicit drug consumption have contributed successfully to a better understanding of drug epidemics and their control via an optimal mix of instruments such as prevention, treatment or law enforcement.

This talk explains why and how tools of dynamic optimization are used to address pressing questions arising in drug policy. Moreover, methodological advances in optimal control theory that have been triggered by solving these problems will be highlighted, e.g., multiple equilibria & SKIBA thresholds. We discuss social interaction mechanisms generating this sort of sensitivity of the optimal solution paths from the initial conditions. Another important type of complex solution structures are persistent limit cycles. A standard two-state production/inventory whose solution consists on a stable oscillation is presented. Surprisingly, it contains several indifference curves and a threefold Skiba point.

#### 2 - Optimal control in the presence of stochastic, impulsive, regime switching and paradigm shifting environments in finance and economy

Gerhard-Wilhelm Weber, Emel Savku

We introduce hybrid stochastic differential equations with jumps and to its optimal control. These hybrid systems allow for the representation of "random" and impulsive regime switches or paradigm shifts in economies and societies, and they are of growing importance in the areas of finance, science, development and engineering and, in future, also in medicine. We present special approaches to this stochastic optimal control: one is based on the finding of optimality conditions and closed-form solutions. We further discuss aspects of information asymmetries, given by delay or insider information.

#### 3 - On the stabilization of control systems by optimization methods

Vakif Dzhafarov, Taner Büyükköroğlu, Özlem Esen

This report is devoted to the stabilization problem for discrete-time control systems. It is well-known that this problem is equivalent to the problem of existence of a stable member in an affine polynomial family. In the parameter space, the stability region is a non-convex set whose convex hull is an open polytope. The extreme points of this polytope are generated by unstable polynomials whose roots lie on the boundary of the stability region, and the number of the extreme points is one greater than the order of the system. Using convex hull technique a necessary condition for the stabilizability is obtained. It is proved that the obtained necessary condition is also sufficient if and only if a suitable game problem has a saddle point. Using linear programming, a tight outer approximation of the set of stabilizing parameters is obtained. It is shown that random search of a stabilizing parameter on

this approximation set gives affirmative results. Possible application to this problem of the moment optimization approach is discussed. The obtained results are illustrated by number of examples.

## ■ FA-25

Friday, 9:00-10:30 - HFB|D

### Demand Side Management

Stream: Energy and Environment

Parallel session

Chair: Magnus Fröhling

#### 1 - Impacts of Constraints in Residential Demand-Side-Management Algorithms - A Simulation-Based Study

Dennis Behrens, Cornelius Rüter, Thorsten Schoormann, Klaus Ambrosi, Ralf Knackstedt

Due to various challenges (e. g. climatic changes, growing population) improvements in managing energy grids are required, for example to consider sustainable but volatile energy generation. Demand-Side-Management (DSM) is one possibility to address these challenges by managing, shifting and controlling loads, saving energy or reducing peaks in energy grids. However, many DSM algorithms make assumptions regarding load characteristics. Thus, real world conditions (e. g. energy loads cannot be moved and paused in any order) are not implemented. Based on a prior review of DSM algorithms as well as several expert interviews we identified five constraints: horizontal and vertical separability of loads, time interval of use, environmental effects, and dependencies between loads. Although several experts highlighted the importance so far no investigation shows the impact of these constraints to DSM algorithms. Therefore, our research question is: Which impact do different constraints have to DSM algorithms? To answer this question, we conducted a simulation with representative DSM algorithms. After implementing each constraint individually, we are able to switch these constraints on and off. As data for our simulation, we used artificial datasets with several predefined households derived by statistical analysis. As a result of comparing the outcomes regarding different key indicators, such as costs, savings, peak-to-average-ratio, and mean-squared-error (MSE), we can conclude that the constraints have an impact on the results. For example, (in the worst case) the savings dropped about 10% and the MSE increased about nearly 40%. Therefore we postulate that these constraints should be used in DSM algorithms for practical application and further evaluation in the future.

#### 2 - Robust online planning of on/off-devices in demand side management

Martijn Schoot Uiterkamp, Marco Gerards, Johann Hurink

As a consequence of electricity generation based on renewable energy sources, the number of devices like electric vehicles and heat pumps is increasing. Generally, the load of these devices is large compared to other house loads. Therefore, this trend may result in much stress on the residential distribution network, which leads to large power peaks inducing energy losses and decreased power quality. One way to overcome these problems is to integrate the new devices in a smart grid and use demand side management (DSM) to flatten the load profile of a house or a whole neighborhood. In this research, we first propose an online load profile flattening algorithm to control an individual on/off-device in a house. This algorithm uses the prediction of a single parameter that characterizes an optimal planning, rather than a detailed prediction of the house profile. This is a major advantage, since obtaining accurate and detailed load profile predictions is difficult. Secondly, we extend this approach to the case where multiple houses coordinate their consumption to attain a common objective. We compare the resulting online algorithm to DSM methods that do use detailed power predictions (i.e., offline algorithms) and show that our method achieves near-optimal solutions.

#### 3 - Production Process Modeling for Demand Side Management

Stefanie Kabelitz, Martin Matke

The electricity supply is growing increasingly dependent on the weather as the share of renewables increases. Different measures can nevertheless maintain grid reliability and quality. These include the use of storage technologies, grid expansion and options for responsiveness

of supply and demand. This paper examines the utilization of responsiveness in production processes subsumed under the concept of demand management, covering two main topics. First, the framework of Germany's energy policy is presented and direct and indirect incentives for businesses to seek as well as provide responsiveness capabilities are highlighted. Converting this framework into a mixed integer program leads to multi-objective optimization. Realistically mapping the different objectives that affect business practices directly and indirectly in a variety of laws is the challenge inherent to this method. Second, a sand processing plant's production processes were modeled. It pumps sand out of a lake, sorts it by grain size, and dries it in a high-energy process. The production processes were modeled in a graph as a flow problem and converted into a mixed integer program. Integrating both continuous and discontinuous batch processes in the model proved to be challenging, as did the modeling of the sorter and a cogeneration unit. Introducing binary variables that represent the starting points of batch processes and directly connecting them with production, flow, storage and energy consumption variables yielded an acceptable problem description with satisfactory computing time.

## ■ FA-26

Friday, 9:00-10:30 - HFB|Senat

### Renewable Energy Sources and Decentralized Energy Systems

Stream: Energy and Environment

Parallel session

Chair: Dominik Möst

#### 1 - Resource allocation problems in decentralized energy management

Johann Hurink, Thijs van der Klaauw, Marco Gerards

Changes in our electricity supply chain are causing a paradigm shift from centralized control towards decentralized energy management. Within the framework of decentralized energy management, devices that offer flexibility in their load profile play an important role. These devices schedule their flexible load profile based on steering signals received from centralized controllers. The problem of finding optimal device schedules based on the received steering signals falls into the framework of resource allocation problems. We study an extension of the traditional problems studied within resource allocation and prove that a divide-and-conquer strategy gives an optimal solution for the considered extension. This leads to an efficient recursive algorithm, with quadratic complexity in the practically relevant case of quadratic objective functions. Furthermore, we study discrete variants of two problems common in decentralized energy management. We show that these problems are NP-hard and formulate natural relaxations of both considered discrete problems that we solve efficiently. Finally, we show that the solutions to the natural relaxations closely resemble solutions to the original, hard problems.

#### 2 - Renewable energy deployment in the UK: a spatial analysis of the opportunities and challenges

James Price

The decarbonisation of electricity production is key to achieving the Paris Agreement goal of limiting global mean surface temperature rise to well below 2°C. It is highly likely that the large scale deployment of variable renewable energy sources (VREs) such as wind and solar will play an important role in meeting this challenge. Given the relatively low spatial energy density of VREs compared to conventional electricity generation, a significant growth in VREs often faces questions around social and environmental acceptance as well as technical limitations. Typically modellers optimise the whole energy system of a country at once at low spatial resolution and so do not consider locally specific social, environmental and technical constraints. Here we seek to study the impact of different levels of these constraints in a UK context, a country which has high public support for VREs at the national level but significant local opposition. To do this we take the following approach: 1) a detailed spatial analysis to develop scenarios of low, medium and high social, environment and technical constraints on VRE deployment, 2) input these into the UK focused cost optimising, high spatial and temporal resolution electricity system model highRES and 3) compare costs, deployment patterns and emissions across scenarios. We find that the costs of highly renewable electricity systems are considerably cheaper if the system optimal sites are developed, i.e.

the model is allowed greater access to areas with a mix of higher capacity factors and a favourable timing of production. Our results suggest that it may be equitable that the money "saved" from developing the better sites is distributed locally in addition to other approaches to seeking community buy-in to VRE projects.

### 3 - Assessing the Impact of Renewable Energy Sources: Simulation Analysis of the Japanese Electricity Market

*Keisuke Yoshihara, Hiroshi Ohashi*

The Great East Japan Earthquake on March 11, 2011 revealed many challenges of Japanese electricity system. The Strategic Energy Plan approved by the Cabinet in April 2014 provides the fundamental direction of energy policy such as lowering dependency on nuclear power generation to the extent possible through energy conservation and introducing renewable energy (RE) sources as well as improving the efficiency of thermal power plants. Among them, introducing RE sources is primarily of importance in terms of improving energy self-sufficiency ratio and reducing the volume of CO<sub>2</sub> emissions. This paper evaluates the impact of RE sources on market outcomes in Japan. We develop a simulation model to compute the kWh-market equilibrium, and conduct simulation exercises for 2015 and 2030 based on the publicly available data. Our model is positioned as part of the optimal generation mix model and enables us to simulate power plants' hourly operations that minimize the total variable cost under several constraints such as demand-supply balances and transmission constraints. Using scenarios proposed by the government, we find that the diffusion of RE sources would lower the kWh-market prices and greenhouse gases by reducing fossil fuel consumption in 2030. It would also mothball many of the thermal power plants, which were active and profitable in 2015. This finding indicates a need for new revenue mechanism such as capacity market that enables power plants to earn revenue from the generation capacity (kW) along with the conventional market mechanism where they earn revenue based on the volume of electricity output (kWh).

## Friday, 10:50-11:35

### ■ FB-22

*Friday, 10:50-11:35 - HFB|A*

### Semi-Plenary Anna Nagurney

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: *Stefan Minner*

#### 1 - Blood Supply Chains: Challenges for the Industry and How Operations Research Can Help

*Anna Nagurney*

Blood is a unique product that cannot be manufactured, but must be donated, and is perishable, with red blood cells lasting 42 days and platelets 5 days. Blood is also life-saving. A multi-billion dollar industry has evolved out of the demand for and supply of blood with the global market for blood products projected to reach \$41.9 billion by 2020. The United States constitutes the largest market for blood products in the world, with approximately 21 million blood components transfused every year in the nation and approximately 36,000 units of red blood cells needed every day.

Although blood services are organized differently in many countries, such supply chain network activities as collection, testing, processing, and distribution are common to all. In this talk, I will focus on the United States, but the methodological tools can be adapted to other countries. Specifically, in the US, the blood services industry has been faced with many challenges in the past decade, with a drop in demand for blood products and increased competition. Revenues of blood service organizations have fallen and the financial stress is resulting in loss of jobs in this healthcare sector, fewer funds for innovation, as well as an increasing number of mergers and acquisitions.

In this presentation, I will overview our research on blood supply chains, from both optimization and game theoretic perspectives. For the former, I will highlight generalized network models for managing the blood banking system, and for the design and redesign for sustainability. In addition, a framework for Mergers & Acquisitions (M&A) in the sector and associated synergy measures will be described. A case study under the status quo and in the case of a disaster of a pending M&A in the US will be presented. Finally, a novel game theory model will be highlighted, which captures competition among blood service organizations for donors.

### ■ FB-23

*Friday, 10:50-11:35 - HFB|B*

### Semi-Plenary Sven Crone

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: *Claudius Steinhardt*

#### 1 - The Rise of Artificial Intelligence in Forecasting? Hype vs real world Success Stories

*Sven F. Crone*

Artificial Intelligence and Machine Learning have become household names, hot topics avidly pushed by the media, with companies like Facebook, Google and Uber promising disruptive breakthroughs from speech recognition to self driving cars and fully-automatic predictive maintenance. However, in the forecasting world, reality looks very different. An industry survey of 200+ companies shows that despite substantial growth of available data, most companies still rely on human expertise or employ very basic statistical algorithms from the 1960s, with even market leaders slow to adopt advanced algorithms to enhance forecasting and demand planning decisions. This reveals a huge gap between scientific innovations and industry capabilities, with opportunities to gain unprecedented market intelligence being missed. In this session, we will highlight examples of how industry thought leaders have successfully implemented artificial Neural Networks and advanced Machine Learning algorithms for forecasting, including FMCG

Manufacturer Beiersdorf, Beer Manufacturers Anheuser Bush InBev, and Container Shipping line Hapag-Lloyd. I will leave you with a vision not of the future, but of what's happening now, and how it can enhance supply chain and logistics planning.

Key learnings:

- What Artificial Intelligence and Machine Learning are, how they work, and their relevance to forecasting
- Real case studies of AI and ML algorithms employed by leading manufacturers
- The power of forecasting algorithms that learn, adapt to context and find hidden insights

## ■ FB-24

Friday, 10:50-11:35 - HFB|C

### Semi-Plenary Dorothea Wagner

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: Rolf Möhring

#### 1 - Route Planning in Transportation - New Results and Challenges

*Dorothea Wagner*

Nowadays, route planning systems belong to the most frequently used information systems. The algorithmic core problem of such systems, is the classical shortest paths problem that can be solved by Dijkstra's algorithm which, however, is too slow for practical scenarios.

Algorithms for route planning in transportation networks have recently undergone a rapid development, leading to methods that are up to several million times faster than Dijkstra's algorithm. For example, for continent-sized road networks, newly-developed algorithms can answer queries in a few hundred nanoseconds; others can incorporate current traffic information in under a second on a commodity server; and many new applications can now be dealt with efficiently. Accordingly, route planning has become a showpiece of Algorithm Engineering demonstrating the engineering cycle that consists of design, analysis, implementation and experimental evaluation of practicable algorithms.

Recently, new aspects like multimodal route planning, personalized journey planning with respect to multiple criteria or energy-aware route planning for electric vehicles come up. This talk provides a condensed survey of recent advances in algorithms for route planning in transportation networks.

and the plan value). This leads to the two basic directions to take for improving the on-time performance:

- stabilize operations, i.e. eliminate erratic disturbances and
- adjust the plan to the mean value of actuals or some value close to the mean value

This implies departing from static scheduling as introduced in the 50ies and still employed by most major railways and introducing a dynamic scheduling approach using OR methods.

The main obstacle to adjusting the schedule to accommodate the systematic errors is an overcrowded train system with very limited room for time-shifting train paths (schedules). We discuss options to solve this impasse within the given framework through a comprehensive optimization approach (unfreeze the system).

## ■ FB-25

Friday, 10:50-11:35 - HFB|D

### Semi-Plenary Christoph Klingenberg

Stream: Semi-Plenaries

*Semi-plenary session*

Chair: Alf Kimms

#### 1 - Improving on-time performance at Deutsche Bahn

*Christoph Klingenberg*

This presentation outlines a framework for improving the on-time performance of a public transport provider from a practitioners' point of view.

In setting the goal for the on-time performance we differentiate between the punctuality for the passenger journey including transfer between trains and the punctuality for each service (train). Besides a differentiated goal you need a simple cost estimate per minute delay, again for a passenger minute and a train minute.

The basic analytic work is to carry out various comparisons of scheduled versus actual values for travel times between stations, stopping times at stations, transfer times between services, maintenance duration or rotation plans for trains. For each analysis, we filter the erratic component (as represented by the standard deviation) from the systematic "plan-error" component (difference between the mean value

## Friday, 11:45-13:15

### ■ FC-01

Friday, 11:45-13:15 - WGS|101

#### Long-haul Transportation

Stream: Logistics and Freight Transportation

*Parallel session*

Chair: *Alexander Kleff*

##### 1 - Learning from the past - Risk Profiler for intermodal route planning in SYNCHRO-NET

*Denise Holfeld, Axel Simroth*

The on-going H2020 project SYNCHRO-NET aims to provide a powerful and innovative platform to identify improvement opportunities by quickly analyzing and calculating the impacts and benefits of smart steaming and synchronomodality on the whole supply chain. The ecoNet shows different trip alternatives, using different transportation modes, and gives the possibility to compare them easily. For this purpose, additional key risk indicators (KRI) are provided in addition to the classic key performance indicators (KPI). In this way the reliability of supply chains can be improved.

To assess risks of a specific route already existing knowledge and experience of nodes and links corresponding to this route should be included in the analysis. Therefore, real-time information is not only used to react and adapt the route if a problem occurs, but also to set up a database in order to analyze different kind of risks for future planning.

A Risk Profiler is developed to identify responsible nodes or links for a cause deviations of the execution of a planned route and to collect this information. This historical database, collected by the system itself, is used to define stochastic information needed in a simulation based Monte Carlo algorithm. Combined with cluster methods different kinds of risks are analysed for new planned routes.

##### 2 - Polynomial time algorithms for truck driver scheduling problems with multiple time windows

*Alexander Kleff*

We study the problem of finding optimal schedules for truck drivers who have to abide by regulations regarding breaks and rests while they visit a sequence of customers. For example, the regulation in the United States stipulates that a truck driver must not continue driving after 8 hours have elapsed unless a break of at least 30 minutes is taken. A feasible schedule respects the driving times between customers, the time windows and the service times at customers, and the appropriate provisions affecting drivers' working hours. Little is known about the complexity of such truck driver scheduling problems, and there is no result in the case of multiple and arbitrarily distributed time windows per customer. We present the first polynomial time algorithms for the problem variants of the European Union and the United States and a planning horizon of one day.

### ■ FC-02

Friday, 11:45-13:15 - WGS|102

#### Delay Management and Route Choice under Delays

Stream: Traffic, Mobility and Passenger Transportation

*Parallel session*

Chair: *Marie Schmidt*

##### 1 - Railway Delay Management in Face of Train Capacity Constraints

*Eva König, Cornelia Schoen*

Delay management for railways is concerned with the question if a train should wait for a delayed feeder train or depart on time. The answer should not only depend of the delay, but there are other factors

to consider, for example capacity restrictions. We present an optimization model for delay management in railway networks that accounts for capacity constraints on the number of passengers that a train can effectively carry. While limited capacities of tracks and stations have been considered in delay management models, passenger train capacity has been neglected in the literature so far, implicitly assuming an infinite train capacity. However, even in open systems where no seat reservation is required and passengers may stand during the journey if all seats are occupied, physical space is naturally limited and the number of standing seats constrained for passenger safety reasons. In this talk, we present the model formulation, solution procedures and results from a numerical experiment analyzing the impact of train capacity restrictions on delay management decisions.

##### 2 - Simulating Passengers and Trains for Better Decisions in Delay Management

*Sebastian Albert, Philipp Kraus, Jörg Müller, Anita Schöbel*

Delay management in rail transportation decides how to react to delays of trains. From a passenger-oriented point of view, the wait-depart decision is crucial: Which of the connecting trains should wait for changing passengers from a delayed feeder train, and which of them should rather depart on time? Furthermore, delays can entail conflicting spatio-temporal overlaps of multiple trains' projected routes. It is therefore also necessary to decide which train gets priority over another when two or more trains simultaneously require the same piece of track.

While possible changes of passengers' itineraries due to missed connections are included in a few publications, the actual physical behaviour of passengers at stations has not been considered within delay management so far: What do travellers do if a transfer is likely to be missed? People running from one platform to another in a hurry can interfere with others, heavy luggage may slow them down and increase the time they need for changing trains, and crowds in the station building may further obstruct their passage. In some situations, particular patterns of passenger flow can even cause additional train delays when, for instance, a steady trickle of people stepping in prevents the doors from closing. In this talk we will show that passengers' behaviour can have significant effects on optimal delay-management decisions.

In order to develop better strategies for delay management, we simulate the results of wait-depart decisions, taking passengers' behaviour into account. We show how such a model can be built in an agent-based setting, combining macroscopic simulation of trains in the railroad network with microscopic simulation of passengers at stations. We illustrate the system by a small example.

##### 3 - The traveler's route choice under uncertainty

*Marie Schmidt, Paul Bouman, Leo Kroon, Anita Schöbel*

A traveler in a periodic public transportation system suddenly faces a disruption of unknown lengths on his planned route. Should he commit to the disrupted route, switch to an alternative route immediately, or wait at the station for a while to see whether the disruption is resolved soon? Robust, stochastic, and online optimization provide different views on the question of an 'optimal strategy' for the traveler in this situation. We discuss how to compute 'optimal' solutions with respect to different concepts for optimization under uncertainty. Furthermore, we compare the recommendations made by robust, stochastic, and online optimization.

### ■ FC-03

Friday, 11:45-13:15 - WGS|103

#### Green Transportation

Stream: Logistics and Freight Transportation

*Parallel session*

Chair: *Martin Hrusovsky*

##### 1 - Efficient Truck Platooning in the Autonomous Driving Possibility: An Artificial Bee Colony Approach

*Abtin Nourmohammadzadeh, Sven Hartmann*

Platooning means driving vehicles behind each other in close proximity as a file and like a string which has been considered as a capable strategy to reduce the cost of transportation companies and also to alleviate the environmental effects of fuel combustion. There are significant benefits for Truck Platooning. Firstly, decreasing the fuel usage by the aerodynamic drag reduction resulted from driving in the slipstream of other vehicles. Then, relieving the traffic congestion because of the shorter inter-vehicle distances. Moreover, by the possibility of



driving all the following trucks by only one driver in the leader truck of each platoon, referred to here as "autonomous driving", a large saving in the drivers' wage can be attained. This research addresses truck platooning in the existence of autonomous driving for the following trucks and with deadlines for the arrival of trucks at their destination. The inputs of this problem are a list of truck duties including origins, destinations and deadlines while the expected outputs are an optimal routing and travel schedule for each truck. A new mathematical model is proposed for the problem and it is solved by LINDO solver for some small and middle sized instances. Since it is proved that this problem is NP-complete, we propose a discrete version of the Artificial Bee Colony algorithm (ABC) to cope with it in large sizes. The computational results indicate that the ABC is able to achieve a valuable average saving of over 20% for problem instances which can be considered as somehow similar to real world cases.

## 2 - Optimizing deliveries of daily goods from small producers by minimization of transport emissions

*Christina Scharpenberg, Jutta Geldermann*

An increasing interest in regional food consumption exists in Germany. Thus, a growing supply of regional food products in German supermarkets can be observed. By consuming local food, one objective is the reduction of transport distances. However, regional food products often originate from small farms and small businesses. These small producers mainly make separate deliveries to the supermarkets by passenger cars or vans. In reality, it has been proved that bundled transport processes in larger vehicles are usually more efficient in terms of environmental protection. Our research objective is to investigate an algorithm which minimizes emissions of the transport process for the delivery of supermarkets by small producers. Transport emissions will be minimized by reducing the specific fuel consumption of a given route. To find the optimal route, we develop an extended vehicle routing problem including heterogeneous vehicles which also takes time and capacity restrictions into account. Further, we consider deliveries and pickups. Therefore, the influence of reusable packaging, which we compare to deliveries with disposable packaging, on the route constellation can be determined.

## 3 - Methodological approaches for green and reliable intermodal transport planning

*Martin Hrusovsky, Emrah Demir, Werner Jammernegg, Tom van Woensel*

The growing transport volumes due to international trade and the limited infrastructure capacity lead in many cases to congestions and other disruptions that result in the delayed delivery of goods. This is especially true for road transport that is the most popular transport mode due to its flexibility and relatively low cost especially for short distances. However, surveys among transport planners show that in addition to cost, also criteria such as reliability and safety are important and there is also an ongoing discussion about environmental impacts of transport. Therefore, other alternatives in addition to road should be considered in transport planning. One of the alternatives is intermodal transport, combining different transport modes where goods are transported in standardized loading units. Since this transport alternative requires higher coordination between the individual transport services, finding reliable routes before the start of the transport is here even more important than for single-mode transport. Thus, we present a mixed-integer linear programming approach for intermodal transport planning taking into account uncertainty in travel times by using different approaches for increasing the reliability of the plans, in particular a sample average approximation and a simulation-optimization approach. The plans can be optimized according to multiple objectives, such as cost, time and emissions and the results of the different approaches are compared based on a real-world case study. Although this approach is capable of covering the most common disruptions, the created plan might still become infeasible due to a major unexpected disruption during transport execution. Therefore, also possible re-planning approaches for these situations will be discussed.

## 1 - Metaheuristics for the vehicle routing problem with backhauls and soft time windows

*Jose Brandao*

The vehicle routing problem with backhauls and soft time windows (VRPBSTW) contains two distinct sets of customers: those that receive goods from the depot, who are called linehauls, and those that send goods to the depot, named backhauls. In each route the linehauls have to be served before the backhauls. To each customer is associated an interval of time (time window), during which each one should be served. If the time window can be violated it is called soft, but this violation implies an additional cost. We solve the VRPBSTW using two different metaheuristics: iterated local search and tabu search. The performance of these two methods is tested and compared using a large set of benchmark problems from the literature. On the other hand, these methods are also compared with other methods for the VRPBSTW that have been published before.

## 2 - An Evolutionary Approach for the Traveling Thief Problem

*Mahdi Moeini, Daniel Schermer, Oliver Wendt*

The Traveling Salesman Problem (TSP) and the Knapsack Problem (KP) are two classical and well-known problems in combinatorial optimization. Recently, a new variant of the TSP has been introduced in which the Knapsack Problem (KP) is integrated in the TSP. The new combinatorial optimization problem is called the Traveling Thief Problem (TTP). In this problem, there is an interdependency between TSP and KP components, e.g., the weight of the knapsack and the gained profit of the picked items have influence on the speed and the final gain the thief as well as his/her TSP tour. This fact (i.e., the interdependency) makes TTP, in comparison to the TSP, particularly difficult to solve. In this study, we are interested in addressing TTP and in solving it by a hybrid evolutionary approach. Our algorithm is based on an effective combination of a Genetic Algorithm (GA), Local Search (LS), and Variable Neighborhood Search (VNS). We evaluate the efficiency of the hybrid algorithm by solving the TTP for some benchmark instances. We compare our results with the best of 21 existing algorithms. According to our observations, the proposed approach is able to improve some of the best known results of the literature.

## 3 - Scheduling an Indoor Football League: a Tabu Search Based Approach

*David Van Bulck, Dries Goossens, Frits Spijksma*

The "Liefhebbers Zaalvoetbal Cup (LZV Cup)", is an amateur indoor football league founded in 2002 and currently involving 477 teams, grouped in different divisions in which each team plays against each other team twice. The goal is to develop a schedule for each of the divisions, which avoids a close succession of matches of the same team in a limited period of time. This scheduling problem is interesting, because matches are not planned in rounds. Instead, each team provides dates on which they can play a home game, and dates on which they can not play at all (e.g. during the Christmas and New Year Period). Furthermore, in contrast to professional leagues, alternating home and away matches is hardly relevant in amateur leagues. The main reason is that the home advantage is quite limited since there are usually few spectators. As the LSV Cup problem turns out highly demanding to solve with integer programming (Gurobi), we have developed a heuristic based on tabu search. The core component of this algorithm solves a transportation problem which schedules (or reschedules) all home games of a team. Besides, we have also developed fix-and-relaxed methods, based on the teams as well as on time intervals. We used the tabu search based method to generate schedules which have been implemented in practice, much to the satisfaction of the participating teams. Overall, the quality of this heuristic is comparable to that of Gurobi, however, the reduced computation time, and the absence of expensive licenses make the heuristic implementation more suitable for (amateur) competitions such as the LZV Cup. In rare occasions where not all matches could be scheduled, the organizers appreciated that our approach outputs a partial solution and the conflicting teams to be contacted.

## 4 - NSGA-II algorithm optimization based workflow scheduling for medical applications in cloud

*Khaled Sellami, Rabah Kassa, Abdelouhab Aloui, Pierre F Tiako*

Cloud computing platform has attracted worldwide attention in a variety of applications like Health Care by deploying large scale medical workflow applications. These applications can be executed cost-effectively in IaaS cloud service model, as it provides scientific users with infinite pool of heterogeneous resources and pay-per-use billing

## ■ FC-04

*Friday, 11:45-13:15 - WGS|104*

## Routing and Scheduling

Stream: Metaheuristics

Parallel session

Chair: *Oliver Wendt*

model. In the proposed work, the medical science applications are mapped to the HaaS resources based on the billing scheme and the billing granularity of the cloud resources. The goal of the proposed work is to schedule medical workflow applications using the non-dominated genetic algorithm (NSGA-II) optimization (for minimizing makespan, cost and energy consumption). The schedule generated by our algorithm is rescheduled based on the task runtime and resource billing granularity. Our approach is validated by simulating a complex Epigenomic medical workflow application.

## ■ FC-05

Friday, 11:45-13:15 - WGS|104a

### Algorithms for Graph Problems (i)

Stream: Discrete and Integer Optimization

*Parallel session*

Chair: *Frauke Liers*

#### 1 - A Local-Search Algorithm for Steiner Forest

*Melanie Schmidt, Martin Groß, Anupam Gupta, Amit Kumar, Jannik Matuschke, Daniel Schmidt, Jose Verschae*

We give a local-search-based constant-factor approximation for the Steiner Forest problem. The algorithm is the second combinatorial algorithm for this problem and brings new techniques to an area which has not seen too many improvements in a while. We hope that it might inspire a combinatorial algorithm for the more general survivable network design problem. Using local search to obtain a constant factor approximation is also interesting because a local search algorithm was crucial for tackling the \*dynamic\* Steiner \*Tree\* problem, and the dynamic Steiner \*Forest\* problem is wide open.

#### 2 - The Primal-Dual Greedy Algorithm for Weighted Covering Problems

*Andreas Wierz, Britta Peis, Jose Verschae*

Many interesting problems can be formulated as so-called integer covering problems. In an integer covering problem, we are given resources and elements. Each element has an associated cost and a non negative weight for each resource. The task is to find a subset of elements (possibly with multiplicity) that covers a demand for each resource. Knapsack cover, set cover, contra-polymatroids and generalized steiner trees are examples of such form. For many problems of this type, a very simple primal-dual greedy algorithm can be used in order to obtain good approximation guarantees. The algorithm uses the dual of the linear relaxation of such a covering problem in order to choose elements that should be added to the solution. If all weights are binary, lots of insight is known regarding problem structures that permit good approximation guarantees. That is, the approximation guarantee can be bounded in terms of properties of the inequality system, such as supermodularity of the right hand side. We investigate similar structural properties in the weighted case. We show that the greedy algorithm has bounded approximation guarantee if the matrix and the right hand side are coupled in a certain way. This coupling is present in all of the applications mentioned above. Our approximation guarantee also matches the best known bounds for all these problems. Lower bound instances matching our approximation guarantee are also provided, showing that the analysis is tight.

#### 3 - Polyhedral Results for Clique Problems with Multiple-Choice Constraints

*Maximilian Merkert, Andreas Bärmann, Patrick Gemander, Frauke Liers, Oskar Schneider*

We consider multiple-choice feasibility problems in which the items chosen in a solution have to fulfill a given pairwise compatibility relation. Motivated by applications from railway scheduling and piecewise linearization of network flow problems, we examine several special cases in which the structure of the underlying compatibility graph allows us to give a complete linear description of the respective polytope. The results are derived, among others, by using graph-theoretic arguments related to perfect graphs. Furthermore, computational experiments show the potential of using our polyhedral results to improve the performance of a state-of-the-art MIP-solver on instances from the aforementioned applications.

## ■ FC-06

Friday, 11:45-13:15 - WGS|105

### Cooperative Truck Logistics

Stream: Graphs and Networks

*Parallel session*

Chair: *Jörg Rambau*

#### 1 - New production approach for European truckload cargo industry

*Andy Apfelstädt*

Production of full truck load (FTL) services has no characteristics of industrialisation yet. Main reason for this is a tight coupling between the working time of ONE driver and the vehicle operating time. Therefore, the value added share of the truck is - due to statutory driving and rest periods, and the applicable law on working hours for the driver - lower than 30%. Due to a sequential multiple occupancy of vehicles used in truckload traffic, a significant increase of their temporal utilization can be achieved. It provides first methodological approaches to the implementation of developed new production forms within newly conceived freight transport networks, especially for truck load traffic.

This talk is about the quantitative results of developing and simulating a new approach.

Based on known planning problems in groupage and less than truckload networks, a FTL- network was conceptually conceived and correspondingly necessarily strategic, tactical and operational objects of planning are described. Further in a theoretical potential analysis with a data set of more than 1.8 millions of shipments of an online based freight market and a corresponding depot network, a quantitative evidence of the effectiveness of the developed and modeled traffic procedures could be provided for the first time. For this moment, the framework conditions were set very simple. Finally, an economical potential analysis, as part of the presentation, revealed a cost advantage of 5%, compared to the classic production form. Therefore, all respective cost and performance factors of different production processes were elaborated and taken into account as well as the expenditure (transport distance) through dynamical routing.

#### 2 - Multi-Routing und Transport-Matching in Cooperative, Full Truckload, Relay Networks

*Bernd Nieberding*

In Germany the actual freight dispatching market consists of small- to middle-sized suppliers, with an average fleet size of 9 vehicles. An important segment of this market is full truck load (FTL), which is described as so-called point-to-point or over-the-road dispatching, with standard curtainsided or box trailers, where the smallest transportation unit is one trailer and a load is directly transported between origin and destination by a single driver. FTL-related production processes are demand-based with short scheduling forerun and lack of planning certainty. Together with an average legally restricted working time of 9,6 hours per day and driver, this situation entails that the operating time of the vehicle and the working time of the driver are directly coupled and the fixed cost intensive vehicle can be utilized in a value-adding manner only for approximately 7 hours a day. A large potential to spread the fixed costs of the vehicle on more productive kilometers is given through the low level of industrialization and standardization of the transport processes related to FTL in German. In this talk we will describe our intended framework, with an cooperative, relay network of different forwarders and processes similar to the processes used in part load dispatching. A mathematical model is used to schedule and route shipments in the network as relays, which allows a restaffing of the truck to enhance the overall calculation. Empty runs play a crucial role in cooperative networks. To this, we describe a matching of transports in the network, which eliminates empty runs. To maximize the matched number of transports handled in the network, each transport is associated with a multiple number of possible network routes, under certain conditions.

#### 3 - MILP-Models for Cooperative Truck Networks

*Jörg Rambau*

If trucks of one company cover a long distance, then during the breaks of the drivers the truck is unproductive. However, companies may build a cooperative network in which trailers can be passed on from driver to driver. Then at least some of the transports may be carried out by putting together only near-home trips of the drivers from and to their depots. Given a number of long- and short-distance trips for full-truckloads and certain rules for the composition of long trips from

near-home trips, we search for the best possible way to replace long-distance trips requiring overnight breaks by a sequence of non-empty near-home trips requiring no overnight breaks. The practical success factors and a basic algorithmic setup for such a business process are discussed in the other talks of this session. In this talk, various Mixed Integer Linear Programming models allowing for various degrees of freedom in the business process and evaluating various objectives are compared on real-world data. The easiest model uses fixed routings for each transport relation whereas a more sophisticated version allows for a set of alternative routings for each transport relation.

## ■ FC-07

Friday, 11:45-13:15 - WGS|106

### Computational Mixed-Integer Programming 5

Stream: Discrete and Integer Optimization

Parallel session

Chair: Ambros Gleixner

#### 1 - Automated Parameter Tuning in SCIP

Ying Wang, Robert Lion Gottwald, Gregor Hendel, Ambros Gleixner, Thorsten Koch

SCIP is a branch-and-cut solver for various classes of optimization problems including mixed-integer programming (MIP) and mixed-integer nonlinear programming (MINLP). To treat instances of practically relevant size, SCIP incorporates numerous solver components such as presolving algorithms, cutting plane separation and primal heuristics, many of which involve a large number of design choices and algorithm-specific parameters. In total, the implemented branch-and-cut algorithm has more than 2100 parameters.

The default values are tuned for a good overall performance on general benchmark sets. Improving the parameter settings for a specific class of problems is a challenging task since an ad hoc, manual tuning processes is often incomplete and time consuming, especially for hard MIP instances. Therefore a systematic and automatized tuning functionality is desirable from both the developers' and users' point of view.

We present an approach that combines parallel sampling and MIP-specific knowledge to guide the search for improving parameter values. It is based on iteratively monitoring several cost measurements to evaluate and compare candidate settings. In addition, the tool considers multiple random seeds to decrease the influence of performance variability on individual evaluations.

#### 2 - Experiments with concurrency in an MINLP solver

Robert Lion Gottwald, Stephen Maher, Yuji Shinano

Portfolio parallelization is an approach that runs multiple algorithms or solver configurations in parallel and terminates when one of them succeeds in solving the problem. This approach is available in the latest release of SCIP, a state-of-the-art academic MINLP solver. We present computational experiments investigating the effectiveness of the approach. We will particularly focus on SCIP's feature of distributed domain propagation. This technique shares global bound changes obtained by domain propagation between solvers in the parallel portfolio.

#### 3 - Adaptive large neighborhood search for MIP

Gregor Hendel

One of the most important qualities of a mixed integer programming solver lies in its ability to quickly provide good incumbent solutions. To this end, modern solvers employ dozens of heuristic algorithms in addition to the search. Among the general purpose primal heuristics, large neighborhood search (LNS) heuristics represent a very effective subclass. Since there is usually little a priori knowledge about the performance of an LNS heuristic for an instance, a solver ideally adapts its mixture of LNS heuristics at runtime.

With the aim to improve over existing, state-of-the-art solver application of LNS strategies, this work introduces an Adaptive Neighborhood Search (ANS) heuristic that employs existing and new LNS techniques and an idea from reinforcement learning. First, a novel LNS heuristic, Graph Induced Neighborhood Search (GINS), is presented. Besides its use as a neighborhood search in itself, a mechanism is introduced that

combines GINS and two other methods to compensate for other neighborhoods that do not reach a desired target fixing rate by themselves.

The second part describes the adaptive behavior of ANS. Besides the control of the individual target fixing rates, ANS learns to rank different neighborhoods based on their success online during search. This approach is motivated by the multi armed bandit problem.

The efficacy of the ANS heuristic is evaluated in a series of computational experiments on instances from academia and industrial applications using the MIP solver SCIP.

## ■ FC-08

Friday, 11:45-13:15 - WGS|107

### Advanced Choice-Based Optimization

Stream: Traffic, Mobility and Passenger Transportation

Parallel session

Chair: Sven Müller

Chair: Knut Haase

#### 1 - A Lagrangian relaxation method for solving choice-based mixed linear optimization models that integrate supply and demand interactions

Meritxell Pacheco Paneque, Shadi Sharif Azadeh, Michel Bierlaire, Bernard Gendron

Integrating customer behaviour in optimization models provides a better understanding of the preferences of the demand-side actors to supply-side operators while planning their systems. On the one hand, these preferences are formalized with discrete choice models, which are the state-of-the-art for the mathematical modeling of demand. On the other hand, the optimization models that are considered to design and configure a system are associated with (mixed) integer linear problems (MILP). The complexity of discrete choice models leads to mathematical formulations that are highly nonlinear and nonconvex in the variables of interest, and are therefore difficult to be included in MILP. In this research, we present a general framework that overcomes these limitations and is able to integrate advanced discrete choice models in MILP. Since the formulation has been designed to be linear, the price to pay is its high dimension, which results in a computationally expensive problem. To address this issue, and given the underlying structure of the model, we propose a Lagrangian relaxation method by identifying two subproblems with common variables: one concerning the choices of customers and another concerning the design variables of the operator. A subgradient method is characterized in order to approximate the associated Lagrangian dual.

#### 2 - Choice Based Revenue Management with Flexible Substitution Patterns

Sven Müller, Frauke Seidel, Knut Haase

In this paper we present a new single-leg choice based (airline) revenue management (CBRM) optimization model with flexible demand substitution patterns between fare classes. The respective demand model is based on individual utility values that, in sum, represent demand for the choice of airline tickets in certain fare classes. We particularly focus on non-constant substitution between alternatives to capture shifts in demand between alternatives that share common unobserved characteristics from the decision makers perspective. Thus, we are able to relax assumptions applied to revenue management optimization models that employ the multinomial logit demand model. We embed a general random utility model in a simulation-based mixed-integer linear program for revenue maximization. Thereby, we determine the prices for - and the availability of - each fare class and guarantee an optimal allocation of bookings to offered fare classes. We are able to solve instances up to 200 bookings (close) to optimality using GAMS/CPLEX. By applying an nested logit demand model we find that revenues are increased compared to the application of the multinomial logit model. In section 2 we discuss that applying multinomial logit demand models is usually not appropriate due to the restrictive assumptions. We investigate the loss in revenue due to inappropriate demand models by a series of numerical studies.

### 3 - Supply chain contract design under asymmetric information: a multi-nominal logit model

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 a multi-nominal logit model.

## ■ FC-09

Friday, 11:45-13:15 - WGS|108

### New Variants of the Traveling Salesman Problem Motivated by Emerging Applications (i)

Stream: Discrete and Integer Optimization  
Parallel session

Chair: Philipp Hungerländer  
Chair: Anja Fischer

#### 1 - Optimal Algorithms for an Extended Version of the Knight's Tour Problem

Michael Firstein, Philipp Hungerländer, Anja Fischer

We present the Traveling Salesman Problem with forbidden neighborhoods (TSPFN) with a radius of length two that is closely related to the well-known knight's tour problem. The TSPFN is an extension of the Euclidean TSP in the plane where direct connections between points that have distance two or less are forbidden.

The TSPFN is motivated by an application in laser beam melting. In the production of a workpiece in several layers it is possible to reduce the internal stress of the workpieces by not allowing the consecutive heating of points that are close to each other. The points in this application are typically arranged on grids that are nearly regular. Hence in this presentation we examine the TSPFN on a regular grid that can also be interpreted as a chessboard with respective dimensions.

For the TSPFN with a radius of length two direct connections between points that have distance greater than two are allowed. This means that feasible steps of minimal length between two points on regular grids are knight's moves. Hence if a knight's tour can be constructed on a certain chessboard, this knight's tour is a feasible and optimal solution for the TSPFN with a radius of length two on the respective regular grid.

We connect the existing algorithms for the knight's tour problem with newly developed methods to solve the TSPFN with a radius of length two on grids with arbitrary dimensions. In most cases our methods are based on the construction schemes used for solving knight's tour problem, i.e. we connect special tours on grids with small dimensions to generate optimal TSPFN tours on grids with arbitrary dimensions. For some grid dimensions we design completely new approaches that also run in polynomial time.

#### 2 - The Traveling Salesperson Problem with Forbidden Neighborhoods on Regular 2D and 3D Grids

Anna Jellen, Philipp Hungerländer, Anja Fischer

We suggest and examine an extension of the Traveling Salesperson Problem (TSP) motivated by an application in mechanical engineering. The TSP with forbidden neighborhoods (TSPFN) with radius  $r$  is asking for a shortest Hamiltonian cycle of a given graph  $G$ , where vertices traversed successively have a distance larger than  $r$ .

The TSPFN is motivated by an application in mechanical engineering, more precisely in laser beam melting. This technology is used for building complex workpieces in several layers, similar to 3D printing. For each layer new material has to be heated up at several points. The question is now how to choose the order of the points to be treated in each layer such that internal stresses are low. Furthermore, one is interested in low cycle times of the workpieces. One idea is to look for a short Hamiltonian cycle over all layers that does not connect points that are too close so that the heat quantity in each Region is not too

high in short periods. In particular in the instances resulting from this application the layers are rectangular and nearly regular grids.

In this presentation we consider the TSPFN on regular 2D and 3D grids, i.e. adjacent vertices all have the same distance from each other. First we suggest an integer linear programming formulation for the TSPFN. Then we examine the TSPFN with radius 0, 1 and square root of 2 on regular 2D and 3D grids and determine construction schemes for optimal tours for these cases. In particular the construction schemes for the 3D case build nicely on the optimal tours for the 2D case.

#### 3 - A linear-time approximation algorithm of the MSTSP for regular grids

Isabella Stock, Jörg Rambau

The Maximum Scatter Traveling Salesman Problem (MSTSP) aims to find a tour through a set of nodes such that the shortest appearing edge is as long as possible. In general, this optimization problem is NP-complete. We present a linear-time algorithm F-Weave( $m,n$ ) for nodes on a two-dimensional ( $m \times n$ )-grid with Euclidean distances. It is an extension of a procedure from Arkin et al. which computes an optimal solution for nodes in one line. F-Weave( $m,n$ ) returns an optimal solution of the MSTSP for most grid sizes; for the remaining cases, we can prove asymptotical optimality of F-Weave( $m,n$ ). This algorithm can be extended to a three-dimensional grid, conserving optimality for more than half of all possible grid-sizes. For the remaining grid sizes approximation algorithms can be deduced. At the same time, F-Weave( $m,n$ ) is asymptotically optimal for the "TSP with forbidden neighborhoods" (TSPFN) with a specific minimum edge length which equals the length of the shortest edge of F-Weave( $m,n$ ). In the TSPFN, the shortest tour through a given set of nodes is required such that the used edges are longer than a minimum length. This work was motivated by a minimization of deflections and production times in selective laser melting.

## ■ FC-10

Friday, 11:45-13:15 - WGS|108a

### Approximation Algorithms

Stream: Discrete and Integer Optimization  
Parallel session

Chair: Sven Krumke

#### 1 - Balanced Optimization with vector costs - a computational study

Annette Ficker, Frits Spieksma, Gerhard J. Woeginger

An instance of a balanced optimization problem with vector costs consists of a ground set  $X$ , a cost vector for every element of  $X$ , and a system of feasible subsets over  $X$ . The goal is to find a feasible subset that minimizes the spread (or imbalance) of values in every coordinate of the underlying vector costs. Balanced optimization problems with vector costs constitute a family of optimization problems; one member of this family is the known balanced assignment problem. For many balanced optimization problems with vector costs, we show that there exists a 2-approximation algorithm; this approximation factor is proven to be best-possible in many cases (unless  $P=NP$ ). For the balanced assignment problem with vector costs we perform a computational study. The goal of this computational study is twofold: (i) to investigate the performance of the proposed algorithm performs on randomly generated instances - how does the worst-case ratio compare to the performance found for the generated instances, and (ii) to find out how different characteristics of an instance (length of a vector, distribution of the costs, ...) impact the performance of the algorithm, both in solution quality and running time. To achieve these goals, we compare the outcomes with other heuristics that have been proposed in literature, and we compare the outcomes with optimum solutions.

#### 2 - A FPTAS for the parametric knapsack problem

Sven Krumke, Michael Holzhauser

We investigate the parametric knapsack problem, in which the item profits are affine functions depending on a real-valued parameter. The aim is to provide a solution for all values of the parameter. It is well-known that any exact algorithm for the problem may need to output an exponential number of knapsack solutions. We present a fully polynomial-time approximation scheme (FPTAS) for the problem that, for any desired precision  $\epsilon$ , computes  $(1 - \epsilon)$ -approximate solutions

for all values of the parameter. This is the first FPTAS for the parametric knapsack problem that does not require the slopes and intercepts of the affine functions to be non-negative but works for arbitrary integral values. Our FPTAS runs in strongly polynomial-time. Even for the special case of positive input data, this is the first FPTAS with a strongly polynomial running time.

## ■ FC-11

Friday, 11:45-13:15 - WGS|005

### Analysis and Optimization of Road Traffic

Stream: Traffic, Mobility and Passenger Transportation  
*Parallel session*

Chair: *Elmar Swarat*

#### 1 - TWT Map Kernel - simulation based routing for field test planning and technical proof of automotive developments

*Bernhard Wieland, Victor Fäßler, Melanie Kluge, Alexander Raufeisen*

A modern vehicle goes through intensive test cycles before market maturity is reached. It is tested and technically proved in hundreds of thousands of kilometers in most diverse environments. The costs are immense and increasing with additional functionalities of modern vehicles. Can field tests be organized more effectively using digital methods?

We developed a special graph structure to represent relevant map data: the TWT Map Kernel. It includes the road network with connections and restrictions as well as properties such as distance, slope or traffic signs. Parametrizable models of vehicle, driver, traffic and weather are used to generate driving profiles, vehicle simulations are used to evaluate powertrain related quantities.

Critical driving situations are now virtually identified on the map and specific field test scenarios are generated using simulation based routing on graphs. Different methods have been developed to cover different search criteria - from global search of "worst-case" routes (including e.g. the most critical situations) to "fixed source and sink" routes with specific criteria (e.g. a concrete histogram of operating points). Actual field tests are now designed in advance for the impact on certain components to enable a targeted and consistent testing. Redundant measurements are reduced and testing is optimized.

In the presentation, theoretical aspects of the graph structure of the TWT Map Kernel and the routing methods are as well shown as further potentials of the method with concrete examples and practical experiences.

#### 2 - Two portable Linear Programming driven Heuristics for Optimal Toll Enforcement

*Elmar Swarat, Gerwin Gamrath, Markus Reuther, Thomas Schlechte*

We present two heuristics based on linear programming (LP) for a rostering problem. The problem is to optimize mobile control tours for toll enforcement inspectors on German motorways. Their task is to enforce the proper paying of a distance-based toll for all trucks weighting 7.5 tonnes or above. In addition, feasible rosters of the inspectors need to be generated. This leads to an integrated tour planning and duty rostering problem; it is called Toll Enforcement Problem (TEP).

We tackle the TEP by a standard multi-commodity flow model with some extensions in order to incorporate the control tours. The first heuristic, called Price & Branch, is a column generation approach to solve the model's LP relaxation by pricing tour and roster arc variables. Then, we compute an integer feasible solution by restricting to all variables that were priced.

The second contribution is a coarse-to-fine approach. Its basic idea is to project variables to an aggregated variable space, which is much smaller and belongs to a coarse version of the original problem. We aim to spend as much algorithmic effort in the coarse model as possible and to only dive into more detail, i.e., in the fine model, if it turns out to be necessary.

For both heuristic procedures we will show that feasible solutions with high quality can be computed even for very large industrial instances. Finally, it turns out that both ideas are portable in the sense that they can be applied to other combinatorial optimization problems as well.

#### 3 - Flexible mobility on demand: integrated choice models and optimization

*Shadi Sharif Azadeh, Bilge Atasoy, Yousef Maknoon, Michel Bierlaire, Moshe Ben-Akiva*

One of the main challenges of operation managers is to decide about how to offer a mix of products to the customers at a given time with the objective of maximizing the expected revenue as well as maximizing the customers' satisfaction. The expected revenue from an offer set is defined by the price and the demand of each of the offered products. This paper introduces the application of such decision making models inside the framework of an innovative transportation concept called Flexible Mobility on Demand (FMOD), which provides personalized services to passengers (e.g. Uber). FMOD is a demand responsive system in which a list of travel options is provided in real-time to each passenger request. The system provides passengers with flexibility to choose from a menu that is optimized in an assortment optimization framework. The allocation of the available fleet to these different services is carried out dynamically based on demand and supply so that vehicles can change roles during the day. The FMOD system is built based on a choice model. The profits of the operators are expected to increase since the system adapts to changing demand patterns. In addition, these tools are significantly beneficial to provide a more sustainable transportation tool especially in countries with less public transport infrastructures.

## ■ FC-13

Friday, 11:45-13:15 - RVH|I

### Forecasting with Artificial Intelligence and Machine Learning

Stream: Business Analytics, Artificial Intelligence and Forecasting

*Parallel session*

Chair: *Sven F. Crone*

#### 1 - Easy-to-implement Cognitive Algorithms for Electricity Spot Price Prediction - An Open-source Approach

*Lissy Langer, Jens Weibezahn, Benjamin Grosse, Lisa Hermann*

Electricity spot market prices are increasingly subjected to strong volatility due to growing shares of fluctuating and intermittent renewable energy sources. Integrating the demand side by the advancement of smart grid technology leads to new possibilities of market participation for players like small manufacturing plants, smart devices or even households, consuming or storing electricity when it is cheapest. Consequently, short-term price prediction becomes more useful and important for more and more market participants. Albeit, not only increased revenues for these players can be expected but also a balancing impact on grid utilization, therefore improving the performance and preventing unnecessary line and storage investments. However, having fewer resources available, these players rely on easy-to-implement algorithms and open-source data to benefit from these developments.

In this paper, hands-on pattern recognition algorithms for the short-term forecast of electricity spot prices are developed using the Python programming language. They are benchmarked for prediction accuracy as well as computational efficiency, aiming to identify useful features that are based on available data, fast to compute, and contain sufficient discriminatory information. Algorithms with a balanced trade-off are developed, providing ready-to-use open-source code to the reader. A special focus lies on the introduction of renewable energy indicators into the feature selection. In addition, other significant - such as seasonal - features related to electricity spot prices are identified. Hence, looking under the hood of these, commonly 'black box', cognitive machine learning algorithms, the effectiveness and efficiency of data selection is improved even for more advanced algorithms.

#### 2 - Neural Network forecasts for time series with Islamic Calendar Seasonality - an empirical evaluation

*Sven F. Crone*

Forecasting for supply chain planning of fast moving consumer goods (FMCG) entails the prediction of monthly industry sales, which regularly exhibit regular time series patterns of levels, trends, seasonality, and combinations thereof. Despite early research suggesting that Neural Networks cannot effectively forecast time series with seasonality and noise (see, e.g. Zhang and Qi, 2005), various research papers (Crone and Kourentzes, 2009; Crone and Dahwan, 2007) as well as the NN3 competition (Crone et al., 2011) have since refuted these findings. However, whilst past studies and competitions have considered only Gregorian calendar seasonality, none have considered forecasting time series with Islamic Calendars. Gregorian calendars show prominent seasonality from calendar events that fall on the same days, weeks and months every year, e.g. Christmas, New Years, 1st of May, etc. In contrast, the religious and bank holidays of the Islamic calendar follow the moon calendar within 12 months of 29 or 30 days length in a year of 354 days, and thus shift in week and month from year to year. As the Islamic calendar drives consumption patterns, and thus to forecast FMCG demand in the Middle-East, we seek to assess the efficacy of forecasting Islamic seasonality with artificial neural networks. We consider a shallow, standard-architecture of Multilayer Perceptrons specified with metric, binary dummy and sine-cosine seasonality of Islamic Seasonality in comparison to statistical benchmarks methods of exponential smoothing and ARIMA applying a regular Gregorian calendar approach. All methods are assessed in a rigorous empirical evaluation using a fixed multi-step horizon and rolling origins over a representative subset of industry time series.

### 3 - Prognosis of EPEX SPOT electricity prices using artificial neural networks

*Johannes Hussak, Ralph Grothmann, Merlind Weber*

The steadily growing trading volume at the EPEX SPOT day-ahead market for the bidding zone Germany, Austria and Luxembourg reveals the increasing relevance of short-term trading within the European electricity market. Simultaneously, high price volatility due to a growing share of intermittent power sources can be observed. Therefore, accurate price forecasts are essential for optimal trading strategies.

In this work, robust, but accurate forecast models to predict the day-ahead price at the EPEX SPOT market using artificial neural networks (ANNs) are developed. In contradiction to many other papers, a large number of possible influencing factors from different countries and on different geographical levels are considered and their impact on the market is evaluated based on a sensitivity analysis. A wide variety of different deep and recurrent neural network setups are deployed and tested. The study identifies the superiority of deep and error correction neural networks (ECNNs) in different seasons throughout the year 2016. The knack of a hybridization of both model setups proves to be the most accurate prediction model.

Since peak prices are hard to predict with these models, a quantile-based scaling approach derived from the field of meteorology and hydrology is applied as a correction factor to get the final model results. Using this technique, a further enhancement in prediction accuracy especially at peak prices is achieved.

The overall prediction errors are on a very low level compared to the actual literature and can effectively be used to optimize offers placing at the EPEX SPOT day-ahead market.

goods. In a first step, a data-driven approach is used to measure substitution effects and to estimate sales probabilities in competitive markets. In a second step, we use a dynamic model to compute powerful heuristic feedback pricing strategies, which are even applicable if the number of competitors' offers is large and their pricing strategies are unknown.

### 2 - Optimal dynamic pricing and lot-sizing for deteriorating items when demand and deterioration are exposed to randomness

*Maryam Ghoreishi, Christian Larsen*

Most published works concerning dynamic pricing and lot-sizing for deteriorating items assume that the inventory system can be modeled as a deterministic system, though most often both the deterioration and the demand process must be assumed to be stochastic. Therefore, in this paper, we develop a problem of dynamic pricing and lot-sizing where demand and deterioration are exposed to randomness. This stochastic model is based on Markov decision theory. We assume that the inter-arrival times follow an Erlang distribution. We find the optimal dynamic price policy by using the value-iteration algorithm and in an outer loop we find the optimal lot-size. We assume that at any time an arriving customer has a reservation price that is perceived by the retailer to be a random variable and the customer only will demand a unit if his reservation price is larger than or equal to the announced price. For the special case with Exponential distributed inter-arrival times, we demonstrate how to do the joint optimization (pricing and lot-sizing) using the policy-iteration algorithm. These models are developed under the assumption that the replenishment lead-time is zero. Next, we extend our model also to assume Erlangean distributed lead-times and we find the optimal price policy by using the value-iteration algorithm and in two outer loops we find the optimal lot-size and reorder point. In addition to our model developments, we also do some numerical investigations. For the case of zero lead-time we investigate whether the lot-sizing and pricing decisions can be decomposed. We observe that this decomposition can lead to a negligible difference if the non-optimal order quantity is close enough to the optimal one.

### 3 - Time-Consistent, Risk averse Dynamic Pricing

*Jochen Gönsch, Rouven Schur, Michael Hassler*

Many industries use dynamic pricing on an operational level to maximize revenue from selling a fixed capacity over a finite horizon. Classical risk neutral approaches do not accommodate the risk aversion often encountered in practice. When risk aversion is considered, time-consistency becomes an important issue. However, there is no consensus in the literature on its definition, as several contradicting properties are desirable. In our approach, we use a nested risk-measure to ensure that decisions only depend on states that may realize in the future. In this context, we use the risk measure Conditional Value-at-Risk (CVaR), which recently became popular in areas like finance, energy or supply chain management. A result is that the risk averse dynamic pricing problem can be transformed to a classical, risk neutral problem. To do so, a surprisingly simple modification of the selling probabilities suffices. Thus, all structural properties carry over. In addition, we show additional, risk-related properties. Moreover, we show that the risk averse and the risk neutral solution of the original problem are proportional under certain conditions. This has straightforward implications for practice. On the one hand, it shows that existing dynamic pricing algorithms and systems can be kept in place and easily incorporate risk aversion. On the other hand, our results help to understand many risk averse decision makers who often intuitively use "conservative" estimates of selling probabilities or discount optimal prices.

## ■ FC-14

*Friday, 11:45-13:15 - RVH|II*

### Dynamic Pricing

Stream: Pricing and Revenue Management

*Parallel session*

Chair: *Jochen Gönsch*

#### 1 - Stochastic Multi-Product Pricing under Competition

*Rainer Schlosser*

Many firms are selling different types of products. Typically sales applications are characterized by competitive settings, limited information and substitution effects. The demand intensities of a firm's products are affected by its own product prices as well as the competitors' product prices. Due to the complexity of such markets, smart pricing strategies are hard to derive. We analyze stochastic dynamic multi-product pricing models under competition for the sale of durable

## ■ FC-17

*Friday, 11:45-13:15 - RBM|2204*

### Scheduling and Staffing 2

Stream: Project Management and Scheduling

*Parallel session*

Chair: *Alexander Haupt*

#### 1 - Multi-objective large-scale staff allocation

*Karsten Lehmann, Harry Edmonds*

We work with a company that has a team of 10 people who spend 2 months manually assigning up to 1,000 staff to 2,000 of their clients and 10,000 jobs. It is a massive undertaking, in part because the scale of the problem and in part because the problem is multi-objective with 54 hard and soft business rules. This problem can be formulated as a large-scale scheduling problem. In our work, we demonstrate that by utilising optimisation methods we can unlock enormous savings in company man-hours while finding solutions with superior quality. In this talk, we will outline the heuristic and exact approaches we utilised, describe some of the many challenges of such a real-world problem, and show how we overcame them.

## 2 - A Bi-criteria Formulation of the Ship Crew Scheduling Problem with Resting Hours Constraints

*Anisa Rizvanolli, Alexander Haupt*

In the paper "Efficient Ship Crew Scheduling complying with Resting Hours Regulations"(presented at the OR Conference 2016) the ship crew scheduling problem with rest hours constraints has been introduced and a mathematical formulation has been presented with the aim of determining the minimal crew needed for the safe ship operation during a given voyage. The safety of a ship is guaranteed by appropriately qualified seafarers and by a schedule which complies with the resting hours rules determined by the Maritime Labour Convention (MLC). In the mixed integer linear program these rules are represented as hard constraints. In reality some of these rules can be broken at a given level. The trade-off between the optimal crew and the compliance of this crew with the rest hours rules is crucial for the decision making process. In order to determine and analyze the trade-off the computation of the Pareto front is needed. Therefore a bi-criteria formulation of the ship crew scheduling problem with resting hours constraints will be presented in this paper. Numerical experiments with real data will be presented.

## ■ FC-18

*Friday, 11:45-13:15 - RBM|2215*

### Timetables and Aircraft

Stream: Project Management and Scheduling  
*Parallel session*

Chair: *Dries Goossens*

## 1 - A Two Stage Stochastic Program for Virtual Course Timetabling Problem

*Cristian David Ramirez Pico, Edna Rocío Pérez Malaver*

The Course Timetabling Problem has been studied in several ways, both varying the features and constraints of the problem, and also testing different solution methods. This research proposes a model for the Virtual Course Timetabling Problem which considers random demand, since the students can take their sessions at any moment and any place only using their laptops. We propose a Two Stage Stochastic Program which in the first stage optimizes the scheduling decisions; for professors, courses and sessions; while the second stage allows us to represent the number of students out of lessons in multiple scenarios of demand. The objective is to minimize the expected cost including scheduling and a penalization for rejected students. A key constraint arises from sessions' capacity to calculate the number of rejected students per scenario. We use commercial software and CPLEX solver to obtain optimal solutions. We conduct computational experiments for several instances with different sizes to conclude about the capacity of the solution method to find optimal solutions, and to present practical conclusions for its application.

## 2 - Conference scheduling: a personalized approach

*Dries Goossens, Bart Vangerven, Annette Ficker, Ward Passchyn, Frits Spijksma, Gerhard Woeginger*

Scientific conferences have become an essential part of academic research and require significant investments (e.g. time and money) from their participants. Given these investments, it is the responsibility of the organizers to develop a schedule that allows the participants to attend the talks of their interest. Furthermore, confronted with multiple talks of interest scheduled in different sessions, a participant is often forced to move between several sessions in order to attend as many of his or her preferred talks as possible. This phenomenon, to which we refer as "session hopping", is perceived as disturbing by presenters and their audiences.

We present a combined approach of assigning talks to rooms and time slots, grouping talks into sessions, and deciding on an optimal itinerary for each participant. Our goal is to maximize attendance, taking into account the common practice of session hopping. On a secondary level, we accommodate presenters' availabilities. We show that constructing a schedule that maximizes attendance is polynomially solvable for 2 parallel sessions, and NP-hard for 3 or more parallel sessions. We develop a hierarchical optimization approach, sequentially solving integer programming models, which has been applied to construct the schedule of the MathSport (2013), MAPSP (2015, 2017) and ORBEL (2017) conferences.

## ■ FC-19

*Friday, 11:45-13:15 - RBM|3302*

### Sales Planning

Stream: Production and Operations Management  
*Parallel session*

Chair: *Han Hoogeveen*

## 1 - Applying capacity allocation auctions to induce truthful information sharing in sales and operations planning

*Frank Hage, Martin Grunow*

We study a sales and operations planning (S&OP) problem in an intra-organizational S&OP alignment process. Sales persons responsible for separate regions have private information on demand quantity and unit profit. They compete for internal production capacity while aiming to maximize their bonus based on the units sold. This leads to rationing gaming, in which the 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 the asymmetric information and the sales agents' reluctance to share their private information. The proposed capacity allocation mechanism leads to truthful information sharing and provides a coordinated outcome. Finally, we extend the mechanism to address the dynamic capacity allocation problem.

## 2 - Deciding how many cuttings to cut from a mother plant: Combining Linear Programming and Data Mining

*Han Hoogeveen*

We study a problem that plays an important role in the flower industry: we must determine how many mother plants are required to be able to produce a given demand of cuttings. This sounds like an easy problem, but working with living material (plants) introduces complications that are rarely encountered in optimization problems: the constraints for cutting such that the mother plant remains in shape are not explicitly known.

We have tackled this problem by a combination of data mining and linear programming. We apply data mining to infer constraints that a cutting pattern, stating how many cuttings to harvest in each period, should obey, and we use these constraints in a linear programming formulation that determines the minimum number of mother plants necessary. We then consider the problem of maximizing the total profit given the number of mother plants and show how to solve it through linear programming.

## ■ FC-20

*Friday, 11:45-13:15 - RBM|4403*

### Food Supply Chains

Stream: Supply Chain Management  
*Parallel session*

Chair: *Martin Grunow*

### 1 - An integrated loss-based optimisation model for apple supply chain

*Parichehr Paam, Regina Berretta, Mojtaba Heydar*

Food supply chain (FSC) refers to the processes from production to delivery of food from farmers to customers. It differs from other kinds of supply chains in terms of the perishable nature of food, variability in its price and demand, consumer awareness toward food security, and its dependency on the climate. Among the existing FSCs, the agricultural fruit supply chain has been paid the least attention. The fact that the quality of fruits deteriorates along supply chain processes and the lack of planning in different supply chain stages can bring about food loss, which has an impact on food security, insufficiency and profitability. Therefore, reducing food loss will bring important benefits not only to FSC companies, but also to society regarding food provision. The purpose of this paper is to present a dynamic mathematical model for apple supply chain in Australia in order to manage inventory flows in different types of storage rooms for apples from different harvesting periods. Food loss-related decision variables are defined to quantify the amount of apple losses in each type of storage based on the time gap between the harvest and delivery. The objective function of the model is total cost minimization, including penalty costs for apple losses. The model is implemented on a real industrial case study to show its applicability and is solved by GUROBI optimization software of mathematical programming problems.

### 2 - A decision support model for sustainable management of catering supply chains

*Cagri Sel, Mustafa Çimen, Mehmet Soysal*

The problem of food waste is currently on an increase and identifying sustainable solutions is a necessity in food supply chain management. Hereby, the purpose of this study is to introduce a decision support model for an environmentally conscious catering supply chain. Demand uncertainty has an impact on food waste in the catering sector. To address this problem, we develop a mixed integer linear programming model that accounts for Poisson distributed demand. The uncertain demand is estimated by a simulation. The key performance indicators of the model are the total waste and total shortage. These indicators enable to assess the sustainability performance of the catering supply chain. The numerical study reflects real settings from a catering organization of a University cafeteria in Turkey. The added value of the proposed decision support model has been shown through the analysis on the base case.

### 3 - Simulating fresh food supply chains by integrating product quality

*Magdalena Leithner, Christian Fikar*

The logistics of perishable goods differs significantly from non-perishable items due to various sources of uncertainties related to seasonable fluctuating supply and demand, unpredictable weather conditions that influence harvest time as well as quality and quantity of the products. Consequently, supply chain designs have to be accurately adapted to the individual product characteristics and cope with uncertainties to reduce food losses and maintain good qualities. Operational research models represent powerful tools to handle the growing complexity and uncertainties of fresh food supply chains. This work focuses on the integration of product quality in supply chain design and aims to minimize food losses during storage and transport. A generic keeping quality model, which models quality losses based on storage temperatures and durations, is implemented in a discrete event simulation. Furthermore, transport routes are optimized to either minimize food losses, maximize qualities or reduce driving distances based on decision makers' preferences. To test the model, the strawberry supply chain in Lower Austria - beginning at the farm and ending at the retail stores - is investigated. The impact of integrated shelf-life information in stock rotation schemes, varying cold chain designs and fleet configurations of producers and warehouses are discussed. In addition, the impacts on food losses are analyzed and the optimized transport routes of various objective functions are compared. Results indicate that stock rotation schemes, which integrate product qualities, the integration of cooling conditions at the producers' location as well as adequate truck capacities and fleet sizes can substantially reduce food losses.

### 4 - Impact of shelf life on the trade-off between economic and environmental objectives: a dairy case

*Bryndís Stefánsdóttir, Verena Depping, Martin Grunow*

Consumer awareness of product sustainability has increased significantly. Especially in the food sector, manufacturers introduce more environmentally sustainable manufacturing processes. However, these often go along with a reduction of product shelf life, which negatively

affects the economic performance due to limited storage duration. We systematically analyze the impact of shelf life on the trade-off between economic and environmental performance of dairy products. We develop a multi-objective optimization model, covering profit and the relevant environmental indicators. A real-life case study is used to contrast traditional milk powders against novel milk concentrates. Concentrates require less energy in processing but have a shorter shelf life. Environmental impacts of the products are determined through a detailed life cycle assessment. Furthermore, objective reduction with the delta-error method is carried out to identify relevant trade-offs. To capture the impact of price uncertainty, the optimization model is implemented in a rolling horizon scheme, in which skim milk powder futures traded at the EEX AG are used as price predictors. Our numerical investigation based on historical data shows the extent, to which the volatility in historical product prices affected the economic evaluation of powders and concentrates. Due to their longer shelf life, powders are economically preferable in periods of large price fluctuations.

## ■ FC-22

*Friday, 11:45-13:15 - HFB|A*

### MCDM 7: Economics and Finance

Stream: Decision Theory and Multiple Criteria Decision Making

*Parallel session*

Chair: *Amir Abbas Najafi*

#### 1 - Evaluating of e-Commerce Risks in the Framework of Capital Asset Pricing Model

*Gökçe Candan*

E-commerce, which is the most important part of the digital economy with developing information technologies, is the physical and digital delivery of products sold over the internet. The reliability of information in the digital economy and the quality of service increase the reliability of the e-commerce companies and it is observed that the shares of companies that deal with e-commerce gain importance in this direction. In the investment market, individuals and firms tend to prefer the arguments that have the lowest risk level to direct their investments and that will provide the highest return against this low risk. By starting from this requirement, the relationship between the risk of a financial asset and its expected effect has emerged by the Capital Asset Pricing Model in a more comprehensive scientific manner. The market (systematic) risks predicted from the Financial Asset Pricing Models are expressed in econometric and statistical meaning and also give the investors the opportunity to direct their investments in this market. In this study, the relationship between risk and expected returns of financial assets is presented by using daily returns data of eBay and Amazon companies' shares, and the risk situation between the two firms is compared.

#### 2 - A novel bi-objective safety-first model for portfolio optimization

*Amir Abbas Najafi, Tahere Hayati*

This research follows the aim of developing a new model for portfolio selection problem using safety first models. Two objective functions of the model are Roy's safety-first criterion and Kataoka's safety-first criterion which are two most popular models in portfolio optimization of modern finance. This problem is first mathematically formulated as a bi-objective model. Then, two multi-objective metaheuristic algorithms are proposed to find Pareto solutions. The parameters of the proposed algorithms are statistically tuned. The performances of the algorithms are evaluated on a set of instances. Finally, we come up with the results to compare these algorithms through solving the instances.

## ■ FC-23

*Friday, 11:45-13:15 - HFB|B*

### Algorithmic Pricing (i)

Stream: Game Theory and Experimental Economics

*Parallel session*

Chair: *Felix Fischer*



## 1 - Sequential Posted Price Mechanisms with Correlated Valuations

Bart de Keijzer

We study the revenue performance of sequential posted price mechanisms and some natural extensions, for a setting where the valuations of the buyers are drawn from a correlated distribution. Sequential posted price mechanisms are conceptually simple mechanisms that work by proposing a "take-it-or-leave-it" offer to each buyer. We apply sequential posted price mechanisms to single-parameter multi-unit settings in which each buyer demands only one item and the mechanism can assign the service to at most  $k$  of the buyers.

For standard sequential posted price mechanisms, we prove that with the valuation distribution having finite support, no sequential posted price mechanism can extract a constant fraction of the optimal expected revenue, even with unlimited supply. We extend this result to the case of a continuous valuation distribution when various standard assumptions hold simultaneously (i.e., everywhere-supported, continuous, symmetric, and normalized (conditional) distributions that satisfy regularity, the MHR condition, and affiliation). In fact, it turns out that the best fraction of the optimal revenue that is extractable by a sequential posted price mechanism is proportional to the ratio of the highest and lowest possible valuation.

We prove that a simple generalization of these mechanisms achieves a better revenue performance; namely, if the sequential posted price mechanism has for each buyer the option of either proposing an offer or asking the buyer for its valuation, then a fraction of the optimal revenue can be extracted that is inversely proportional to the "degree of interdependence"  $d$  in the valuation distribution. The latter value  $d$  is a parameter that ranges from complete independence ( $d = 0$ ) to arbitrary dependence ( $d = \text{number of buyers}$ ).

## 2 - Posted price mechanisms for a random stream of customers

Tim Oosterwijk, José Correa, Patricio Foncea, Ruben Hoeksma, Tjark Vredeveld

Posted price mechanisms constitute a widely used way of selling items to strategic consumers. Although suboptimal, the attractiveness of these mechanisms comes from their simplicity and easy implementation. In this talk, we investigate the performance of posted price mechanisms when customers arrive in an unknown random order. We compare the expected revenue of these mechanisms to the expected revenue of the optimal auction in two different settings. Namely, the nonadaptive setting in which all offers are sent to the customers beforehand, and the adaptive setting in which an offer is made when a consumer arrives. For the nonadaptive case, we obtain a strategy achieving an expected revenue within at least a  $1-1/e$  fraction of that of the optimal auction. We also show that this bound is tight, even if the customers have i.i.d. valuations for the item. For the adaptive case, we exhibit a posted price mechanism that achieves a factor 0.745 of the optimal revenue, when the customers have i.i.d. valuations for the item. Along the way, we prove a basic result about Bernoulli random variables that we believe can be of independent interest.

## 3 - Revenue Gaps for Discriminatory and Anonymous Sequential Posted Pricing

Felix Fischer, Paul Duetting, Max Klimm

We consider the problem of selling a single item to one of  $n$  bidders who arrive sequentially with values drawn independently from identical distributions, and ask how much more revenue can be obtained by posting discriminatory prices to individual bidders rather than the same anonymous price to all of them. The ratio between the maximum revenue from discriminatory pricing and that from anonymous pricing is at most  $2-1/n$  for arbitrary distributions and at most  $1/(1-(1-1/n)^n) \leq e/(e-1) \approx 1.582$  for regular distributions. These bounds are tight for all values of  $n$  and can in fact be attained by using one of the discriminatory prices as an anonymous one. For an important class of distributions that includes uniform and exponential distributions we show the maximization of revenue to be equivalent to the maximization of welfare with an additional bidder, in the sense that both use the same discriminatory prices. The problem of welfare maximization is the well-known Cayley-Moser problem, and we use this connection to establish tight bounds on the revenue gap of approximately  $1.037$  for uniform and  $1.073$  for exponential distributions.

## ■ FC-24

Friday, 11:45-13:15 - HFB|C

### Continuous Optimization and Applications

Stream: Control Theory and Continuous Optimization  
Parallel session

Chair: Gerhard-Wilhelm Weber

#### 1 - Decisions on Pricing, Capacity Investment, and Introduction Timing of New Product Generations in a Durable-Good Monopoly

Andrea Seidl, Richard Hartl, Peter M. Kort

The aim of the present paper is to analyze how firms that sell durable goods should optimally combine continuous-time operational level planning with discrete decision making. In particular, a firm has to continuously adapt its capacity investments, but only at certain times it will introduce a new version of the durable good to the market and determine its price. The launch of a new generation of the product attracts new customers. However, in order to be able to produce the new version, production facilities need to be adapted leading to a decrease of available production capacities.

A firm should increase its production capacity most upon introduction of a new product. Then the stock of potential consumers is largest so that then the market is most profitable. The extent to which existing capacity can still be used in the production process for the next generation has a non-monotonic effect on the time when a new version of the product is introduced as well as on the capital stock level at that time.

We briefly discuss the boundary value problem which we use to numerically find a solution of the given problem.

#### 2 - Semi-supervised supports vector machines: A semi-infinite programming formulation

Fariha Umbreen, Muhammad Faisal Iqbal, Faizan Ahmed

In this paper we present the cone programming reformulation of Semi-supervised support vector machine. The current cone programming reformulation relies on doubly non-negative or Semi-definite relaxation. We look at the dual of the cone programming relaxation for solution, which is a copositive program that can be cast as the semi-infinite optimization problem. The discretization method for semi-infinite program is guaranteed to converge with proven convergence rate. We use this fact to our advantage to develop an algorithm to approximate the copositive program underlying Semi-supervised support vector machine. Numerical results are presented to compare our approach with the existing methods for semi-supervised support vector machine.

#### 3 - Extracting the relevant trends for applied portfolio management

Theo Berger

As financial return series comprise relevant information about risk and dependence, historical return series describe the underlying information for applied portfolio management. Although market quotes are measured periodically, the data contains information on short-run as well as long-run trends of the underlying return series. A simulation study and an analysis of daily market prices reveal the relevance of short-run information for applied portfolio management.

## ■ FC-25

Friday, 11:45-13:15 - HFB|D

### Energy and Optimization

Stream: Energy and Environment  
Parallel session

Chair: Dogan Keles

#### 1 - Optimal Looping of Pipelines in Gas Networks

Ralf Lenz, Robert Schwarz

Natural gas is transported through networks of pipelines. Network capacity can be increased by placing new pipe segments parallel to existing ones. In this paper, we present two alternative models for the problem of finding the cost-minimal expansion plan. One allows for pipe segments of arbitrary length, while the other always expands pipes along their entire length. We then compare the feasible regions of these approaches and discuss model properties such as convexity and monotonicity.

## 2 - An optimization algorithm for the planning of virtual power plants

*Lars-Peter Lauen*

In the context of expanding shares of renewable energy, the management of fluctuating power production from wind turbines or photovoltaic cells is becoming a critical part of energy supply. Operators of virtual power plants, which consist of numerous flexible power supply and demand actors to compensate production fluctuations, need to identify the most profitable way to react to the development of prices on the day-ahead and intraday markets for power. As these markets are organized as auctions, both initial bids and reactions to auction results must be considered. On the demand side, flexible power consumption in household applications, industrial processes and electric vehicle charging can potentially be incorporated into virtual power plants. The flexibility of such flexibility options is curtailed by the limited feasibility of operation times, postponements and charging times, e.g. for electric vehicles. On the supply side, both renewable and fossil power plants can be included into the virtual power plant. The extent to which these can be used flexibly is limited e.g. by the available storage capacities in biogas plants. A Python-based algorithm consisting of both cost minimization models for power consumers and revenue maximization models for producers and energy storages is proposed to address the problem.

## 3 - Models and heuristic approaches for a large scale multi-period offshore power-grid extension planning problem

*Philipp Hahn*

The offshore power grid extension planning problem aims at building and locating wind farms in the north sea and dimensioning the power grid connecting them to the onshore grids. The dimensioning of the grid should be in such a way that under different weather conditions and thus, potentially very different in-feeds, the power can always be transported to shore. Additionally, neighboring countries can trade energy which needs to be considered in the dimensioning as well. The goal is to minimize the cost of such a potential grid under several technical, political and environmental constraints. Since this is a long term planning the construction plan should ensure operational intermediate stages. This is a large scale optimization problem due to the huge number of potential locations for wind farms, the variety of technologies that can be used and the large number of different weather scenarios. We model the problem as a network flow problem including (linearized) power flow losses on the lines. Technical equipment (e.g. lines, platforms, converters, etc.) is available in integer quantities and a sufficient amount needs to be installed according to technical constraints. The model is then formulated as a MIP. In order to speed up the branching process, we want to find good initial heuristic solutions. We compute solutions of simplified versions of the problem (e.g. Min-Cost-Flow Formulation) and extend them to a solution of the original instance. Those solutions are used to reduce the size of the branching tree later on. The structure of the problem also allows for decomposition techniques that we investigate as well.

found different optimization problems, such as water network design, pipe optimization, tank optimization, energy minimization or pump scheduling. All those problems have in common that there exist many mathematical optimization models and a variety of different solution methods for each of them. Most research work is evaluated either on few realistic networks that are only available for one special use case or on those few test networks that are available in the literature. These networks are mostly very small and often lack in realistic properties. In order to evaluate models and solution methods and compare them to other research work, it is inevitable to have many different water network models. These models require to be of realistic size and to have realistic properties. In this talk, we present a model generator for water distribution systems. With this generator it is possible to create network models with realistic properties and realistic size. The generator can also control the structure of the network to guarantee a realistic reflection of a water distribution system. To ensure the hydraulic properties in the network we use a hydraulic simulation tool in our generator. Details about the generation process and the application of different use cases will be shown in this talk.

## 2 - An Adaptive Discretization Algorithm for the Design of Water Usage and Treatment Networks

*Sascha Kuhnke, Arie Koster*

In this talk, we consider the design of water usage and treatment systems in industrial plants. In such a system, the demand of water using units as well as environmental regulations for wastewater have to be met. To this end, wastewater treatment systems may be installed and operated to clean the water. The objective of the design problem is to simultaneously optimize the network structure and the water allocation of the system. Due to many bilinear mass balance constraints, this water allocation problem is a nonconvex mixed integer nonlinear program (MINLP). Standard nonlinear solvers have difficulties to even find feasible solutions for larger instances.

We present a problem specific algorithm to iteratively solve this MINLP. This algorithm deals in each iteration with a mixed integer linear program (MILP) and a quadratic constrained program (QCP). First, the MILP approximates the original problem via discretization and its solution provides a suitable network structure. Then, by fixing this network structure, the original MINLP turns into a QCP which yields solutions to the original problem. To improve the accuracy of the generated structure, the discretization of the MILPs is adapted after each iteration based on the previous MILP solution. In many cases where nonlinear solvers failed, this approach leads to feasible solutions with good solution quality in short running time.

## 3 - Design and development of a decision support system for water distribution networks

*Michaela Beckschäfer, Corinna Hallmann*

Drinking water supply systems are important components of the public infrastructure because water fulfills essential functions. A steady supply is required due to the all-purpose need of water in private households as well as in companies and public facilities. Since water consumption per capita on a daily basis in Germany has decreased significantly contrary to forecasts in the last 25 years, many components of the drinking water supply system are not dimensioned to work efficiently. This causes unnecessary costs and therefore the planning of new and the adaptation of existing water supply systems is even more important. We will present the design and development of a decision support system for the planning of water supply networks. The basis for this is an existing prototype upon which the graphical interface and processes are extended and improved. During the usage of different evaluation techniques it becomes clear that the decision support system shows large improvements compared to the prototype. This includes especially the completion of different tasks for the modification and processing of water network models.

## ■ FC-26

Friday, 11:45-13:15 - HFB|Senat

## Water Networks

Stream: Energy and Environment

Parallel session

Chair: Corinna Hallmann

### 1 - Model Generator for Water Distribution Systems

*Corinna Hallmann, Stefan Kuhlemann*

In recent years, the optimization of water distribution systems has gained more and more attention. In the literature, there can be

## Friday, 13:45-15:00

### ■ FD-27

Friday, 13:45-15:00 - HFB|Audimax

### Plenary Lecture and Closing Ceremony

Stream: Plenaries

*Plenary session*

Chair: *Natalia Kliewer*

Chair: *Ralf Borndörfer*

Chair: *Jan Fabian Ehmke*

#### 1 - On Big Data, Optimization and Learning

*Andrea Lodi*

In this talk I review a couple of applications on Big Data that I personally like and I try to explain my point of view as a Mathematical Optimizer - especially concerned with discrete (integer) decisions - on the subject. I advocate a tight integration of Machine Learning and Mathematical Optimization (among others) to deal with the challenges of decision-making in Data Science.

For such an integration I try to answer three questions:

1. What can optimization do for machine learning?
  2. That can machine learning do for optimization?
  3. Which new applications can be solved by the combination of machine learning and optimization?
-

## Awards

Track(s): 24

### Business Analytics, Artificial Intelligence and Forecasting

*Sven F. Crone*

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*Alexander Martin*

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*Thomas Setzer*

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Track(s): 13 14

### Business Track

*Ralf Borndörfer*

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Track(s): 12

### 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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### Game Theory and Experimental Economics

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### Graphs and Networks

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### Logistics and Freight Transportation

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### Optimization under Uncertainty

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