GOR

Gesellschaft für Operations Research e.V.

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90th Meeting of the GOR Working Group

Praxis der Mathematischen Optimierung
("Real World Optimization")

Mathematical Optimization in Traffic

11–12 April, 2013
PTV AG, Karlsruhe, Germany
(http://www.ptvgroup.com/de/)

Organization

Josef Kallrath & Alexander Lavrov & Steffen Rebennack
GOR AG „Praxis der mathematischen Optimierung"

&

Clarissa Strasser
PTV AG, Karlsruhe

Mathematical Optimization in Traffic

Transportation is an economy sector immediately impacted by the globalization and facing a series of challenges related to the unprecedented growth of electronic commerce, emerging smart technologies, strengthening environmental awareness, ever complicated network structures and multimodal transportation, etc. Efficient planning, design and operation of contemporary transportation systems are only possible on the basis of mathematically founded decision methods and techniques. In spite of a plenty of existing formal models, of conducted theoretical and empirical studies, of already operating intelligent vehicles and powerful software tools, the real world is permanently posing new problems in this area, which are often very hard to model, analyze and solve. Classical optimization areas related to transportation, including the network optimization, optimal vehicle assignment and operative control, are supplemented by additional requirements concerning the reduction of energy consumption and environmental pollution, longer transport distances, complex vehicle-to-vehicle interactions, innovative logistics trends such as just-in-time or just in sequence, special features of urban traffic flows, etc.

This meeting offers a forum for discussing these and many other issues in the scope of application of mathematical optimization techniques. Topics in exact (mixed integer programming, branch-and-cut, branch-and-price) and heuristic optimization (evolutionary programming, tabu search, variable neighborhood search, ant colony optimization, etc.) will be treated. In particular, contributions are welcome dealing with: vehicle routing problem, network structuring, vehicle fleet deployment, intelligent transport systems, parking policies, fare structure, congestion reduction strategies, management of non-motorized traffic, modal mix determination, integration of pools or cross docks into network flows, etc.

This two-days event gives an overview of the current state of the art of mathematical optimization methods for traffic.

In talks, each approx. 40 minutes, experts from practice, research institutions or software companies, present selected problems and the corresponding solutions. Speakers' list:

- Jan **Ehmke**, Dr. (Freie University Berlin & Iowa State University):"Minimization of travel times and emissions for city logistics applications: Integration of large travel time databases in time-dependent and stochastic optimization approaches"
- Siegfried **Jetzke**, Prof. Dr. (Ostfalia University of Applied Science, Salzgitter): "Route planning for different time horizons"
- Knut **Haase**, Prof. Dr. (University of Hamburg: "Sales Force Deployment"
- Alexander **Kleff** (PTV Group, Karlsruhe): "Construction Heuristic for a Vehicle Routing Problem with Time-Dependent Functions“
- Sebastian **Knopp** (PTV Group, Karlsruhe): "Time optimization of routes under consideration of restrictions from practice“
- Neele **Leithäuser**, Dr. (Fraunhofer ITWM, Kaiserslautern): "Models and algorithms for considering vehicle scheduling constraints in timetable synchronization problems"
- Dirk **Mattfeld**, Prof. Dr. (TU Braunschweig): "Design of bike sharing systems“
- Teresa **Melo**, Prof. Dr., Thomas **Bousonville,** Prof. Dr., (University of Applied Sciences Saarland): "The impact of data aggregation on distribution planning: A case study"
- Stefan **Nickel**, Prof. Dr. (Karlsruhe Institute of Technology): "New Approaches to territory planning"
- Silvia **Schwarze**, Dr. (University of Hamburg: "Load balancing and equilibria for site-dependent vehicle routing problems"
- Frank **Schulz** (PTV Group, Karlsruhe): "Modern routing algorithms in practice“
- Sebastian **Wehowski** (PTV Group, Karlsruhe): „Welche Herausforderungen sind bei Produkteinführungen von Tourenplanungs-software zu meistern? “

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90. Sitzung der GOR Arbeitsgruppe
Praxis der Mathematischen Optimierung

Mathematische Optimierung im Transportwesen

PTV AG, Karlsruhe, April 11 & 12, 2013

Donnerstag, April 11 - 2013 : 10:00 – 21:30

10:00-10:10 **Opening and Welcome Session** (Matthias Hormuth, Josef Kallrath & Alexander Lavrov)

10:10-10:30 Matthias Hormuth, Vice President Concepts & Solutions Logistics Software – PTV AG, Karlsruhe
Vorstellung der PTV AG

10:30-11:10 **Frank Schulz** – PTV Group, Karlsruhe
Modern Routing Algorithms in Practice

11:10-11:35 ---------------------------- Coffee Break -------------------------------

11:35-12:15 **Prof. Dr. Siegfried Jetzke** – Ostfalia Hochschule, Salzgitter
Route Planning for Different Time Horizons

12:15-13:30 ------------------------- Lunch Break --------------------------------

13:30-14:00 **Sebastian Wehowski** – PTV Group, Karlsruhe
Welche Herausforderungen sind bei Produkteinführungen von Tourenplanungssoftware zu meistern?

14:00-14:50 **Prof. Dr. Thomas Bousonville** – University of Applied Sciences Saarland, Saarbrücken
The impact of data aggregation on distribution planning: A case study

14:50-17:30 **Excursion: Guided Tour through "Karlsruhe Castle"**

17:30-18:30 **Free Discussion Time for the Participants**

18:30-21:30 **Conference Dinner – Hoepfner Burghof (opposite PTV)**

Celebrating the 90th Meeting of our GOR Working Group

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Freitag, April 12 - 2013 : 09:15 – 16:15

09:15-09:55 **Prof. Dr. Stefan Nickel** – KIT Karlsruhe, Karlsruhe
New Approaches to Territory Planning

09:55-10:35 **Prof. Dr. Knut Haase** – Universität Hamburg + GOR AG "Logistik&Verkehr"
Sales Force Deployment

10:35-11:00 ------------------------- Coffee Break --------------------------------

11:00-11:40 **Alexander Kleff** – PTV Group, Karlsruhe
Construction Heuristic for a Vehicle Routing Problem with Time-Dependent Functions

11:40-12:20 **Dr. Silvia Schwarze** – Universität Hamburg, Hamburg
Load Balancing and Equilibria for Site-Dependent Vehicle Routing Problems

12:20-13:30 ------------------------------------ Lunch Break ----------------------

13:30-14:10 **Prof. Dr. Dirk Mattfeld** – TU Braunschweig, Braunschweig
Optimization approaches to the service network design of bike sharing systems

14:10-14:50 **Prof. Dr. Jan Fabian Ehmke** – TU Braunschweig, Braunschweig
Minimization of Travel Times and Emissions for City Logistics Applications: Integration of Large Travel Time Databases in Time-dependent and Stochastic Optimization Approaches

14:50-15:10 ------------------------- Coffee Break --------------------------------

15:10-15:50 **Dr. Neele Leithäuser** – Fraunhofer ITWM, Kaiserslautern
Models and algorithms for considering vehicle scheduling constraints in timetable synchronization problems

15:50-16:20 **Sebastian Knopp** – PTV Group, Karlsruhe
Scheduling Drivers' Breaks and Rests under Additional Time Constraints

16:20-16:30 **Abschlussdiskussion – Ende der Veranstaltung**

The Speakers

Thomas Bousonville received his PhD from the University of Bremen (Germany) for work on Arc Routing and Hybrid Genetic Algorithms. He has five years industry experience in the design and implementation of Supply Chain Management Systems. Before joining the Saarland University of Applied Sciences (HTW) as a professor for logistics and information systems, he worked as Senior Scientist for ILOG (now IBM) in Paris, France. Since 2006 he is lecturing at HTW in specialized study programs in logistics (undergraduate and graduate level). His research interests include vehicle routing and transportation planning as well as supply chain planning and the application of information technology in logistics.

Jan Fabian Ehmke has recently been a visiting PostDoc at the Management Sciences Department of the University of Iowa, USA, where he has worked on robust shortest path and vehicle routing algorithms for city logistics applications. He received his PhD in Business Information Systems from the University of Braunschweig, Germany, in 2011. His research interests are in the area of traffic information systems, especially in the provision and analysis of empirical traffic data for logistics applications in metropolitan areas. To this end, his work focuses on data driven methods from the field of Data Warehousing/Data Mining and Operations Research.

Knut Haase is professor and director of the Institute of Transport Management at the University of Hamburg. He holds degrees in Quantitative Business Administration (diploma), a Ph.D. and the habilitation from the Christian Albrechts University of Kiel. He leads the Transport and Logistics Working Group of the German Operations Research Society.His current research interests are in quantitative approaches to logistics including public mass transit. He is author of numerous papers in various journals.

Siegfried Jetzke is professor for *Technische Grundlagen und Logistik* at the *Ostfalia Hochschule für angewandte Wissenschaften* in Salzgitter. He studied physics and mathematics and received his doctoral degree in theoretical physics with a work on nonlinear processes in laser-atom-interactions. Before becoming engaged in logistics he worked on simulation and optimization problems in genetics as well as transportation problems of nuclear particles. Nowadays he feels to be positioned between the practitioner in production or logistics and the theoretician. His main interest is to find propper descriptions and solutions for real life problems such that available methods and techniques known in mathematics and computer science can be applied. Many questions of interest are due to the very different time scales in logistics, ranging from seconds to years, together with the large spatial distribution of logistical processes a mixture of different approaches supported by a well planned strategy for observations is needed to obtain *good* solutions.

Josef Kallrath obtained his PhD in astrophysics from Bonn University (Germany) in 1989. He is a professor at the University of (Gainesville, FL, www.astro.ufl.edu/∼kallrath), and solves real-world problems in industry using a broad spectrum of methods in scientific computing, from modeling physical systems to supporting decisions processes by mathematical optimization. He has written review articles on the subject, about 70 research papers in astronomy and applied mathematics, and several books on mixed integer optimization, as well as one on eclipsing binary stars.

He leads the Real World Optimization Working Group of the German Operations Research Society. His current research interests are polylithic modeling and solution approaches to solve large-scale or difficult optimization problems, for instance, by decomposition techniques such as column generation, or hybrid methods.

Alexander Kleff is a developer at the department "Logistics Optimisation Components" at PTV Group in Karlsruhe. Prior to that, he worked as a student assistant at the Research Institute for Discrete Mathematics at the University of Bonn where he received his diploma degree in computer science. Currently, he works towards a doctoral degree at the chair for Discrete Optimization and Logistics at Karlsruhe Institute of Technology. His current research interests are in the application of discrete optimisation techniques to problems arising in logistics, especially the vehicle routing problem in its many variants.

Sebastian Knopp is Software Developer at PTV Group in Karlsruhe, Germany. He received his Diploma degree in computer science from the University of Karlsruhe, Germany, in 2006. Since then, he has been working on the implementation and design of algorithms in the field of logistics and digital maps. He was concerned with algorithms for routing in large road networks, map matching and fault tolerant geocoding. His current focuses are practical methods for vehicle routing problems, in particular time scheduling of tours under observation of real world constraints.

Neele Leithäuser studied mathematics at TU Kaiserslautern. In 2012, she finalized her PhD on the integration of vehicle scheduling and transfer optimization in public transport networks. She works at the Optimization department at the Fraunhofer Institute for Industrial Mathematics (ITWM) in Kaiserslautern and is currently engaged in a project on scheduling research projects strategically for a major company.

Dirk Christian Mattfeld received his Ph.D. from the University of Bremen in 1995. Since 2004, he has been a full professor at the University of Braunschweig and the head of the Decision Support Group of the Business Information Systems Institute. Dirk Christian Mattfeld is interested in the interplay of optimization, data analysis and simulation, focusing decision support systems for applications in transportation and logistics. He is an associate editor of the *Journal of Scheduling*, the *International Journal of Information Systems and Supply Chain Management*, the *International Journal of Information and Decision Sciences*, and a member of the Editorial Board Operations and Information Systems of VHB's journal *Business Research.*

Teresa Melo studied applied mathematics at the University of Lisbon (Portugal) and received her PhD in Operations Research from the Erasmus University Rotterdam (The Netherlands). From 1999 to 2007 she worked at the Fraunhofer Institute for Industrial Mathematics (Germany), where she conducted a number of industrial and publicly funded projects on *Supply Chain Management* and *Hospital Logistics.* Since 2007 she is professor of mathematics and statistics at the Saarland University of Applied Sciences (HTW), Germany. Her research interests include logistics network design, health care logistics as well as routing and distribution problems.

Stefan Nickel hat an der Technischen Universität Kaiserslautern Wirtschaftsmathematik studiert und dort 1995 in Mathematik promoviert und 1999 habilitiert. Noch während seiner Habilitation wechselte er an das neu gegründete Fraunhofer ITWM in Kaiserslautern. Von 2003 bis 2009 hatte Herr Nickel eine Professur an der Universität des Saarlandes. Seit 2009 leitet er am KIT gemeinsam mit zwei Kollegen das Institut für Operations Research. Außerdem ist er seit 2011 Direktor am Karlsruher Service Institute (KSRI) sowie Direktor am Forschungszentrum für Informatik (FZI) in Karlsruhe.
Stefan Nickel ist Mitglied des Scientific Advisory Boards des Fraunhofer-Instituts für Angewandte Mathematik (ITWM) in Kaiserslautern. Weiterhin ist er seit 2006 als Editor-in-Chief verantwortlich für die international renommierte Zeitschrift Computers & Operations

Research. Er ist Sprecher des Boards der EURO Working Group on Locational Analysis (EWGLA). Darüber hinaus ist er seit 2013 Vorsitzender der deutschen Gesellschaft für Operations Research (GOR).
Seine Forschungs- und Lehrschwerpunkte sind Standortplanung, Gebietsplanung, Supply Chain Management, Health Care und Online-Optimierung.

Stefan Nickel obtained his PhD in mathematics at the Technical University of Kaiserslautern in 1995. From 1995 to 2003 he was first assistant and then associate professor in mathematics at the Technical University of Kaiserslautern. After a full professor position at the Saarland University from 2003 to 2009 he became one of the directors of the Institute for Operations Research at the KIT in 2009. In 2011 he additionally became one of the directors of the Karlsruhe Service Research Institute (KSRI) and the Research Center for Computer Science (FZI).
Stefan Nickel is also member of the scientific advisory board as well as the management board of the Fraunhofer Institute for Applied Mathematics (ITWM) in Kaiserslautern. Moreover, Stefan Nickel is editor-in-chief of Computers & Operations Research since 2006. He is the speaker of the EURO working group on locational analysis (EWGLA). Furthermore, since 2013 he is the president of the Gesellschaft für Operations Research (GOR).
His main fields of research are facility location, territory design, supply chain management, health-care and online-optimization.

Steffen Rebennack is an Assistant Professor at the Colorado School of Mines, USA. He obtained his PhD at the University of Florida. His research interests are in dimension-reduction techniques for large-scale optimization problems, particularly with applications in power systems, stochastic optimization and global optimization.

Frank Schulz is a software developer at PTV Group in Karlsruhe, Germany. He studied mathematics and computer science at the University of Konstanz. In January 2005 he received his PhD in computer science at the University of Karlsruhe, with a thesis on "Timetable Information and Shortest Paths". Most of his research has been done in the field of algorithm engineering, particularly on shortest path problems. Since 2006 he is working in the team responsible for the routing engine that is used in many products of the PTV Group, such as Map&Guide or SmarTour.

Silvia Schwarze is a Research Assistant at the Institute of Information Systems, University of Hamburg. She received a PhD in Mathematics from the University of Göttingen in 2006. Her research interests are in the fields of logistics and telecommunication with focus on network optimization, games on networks, mathematical programming and metaheuristics.

Sebastian Wehowski Produktmanager Transport + Logistik, PTV AG, SGE Tourenplanung und -optimierung Seit 2006 Produktmanager, Zuvor Geschftsfhrer der WL Logistic Beratung Berlin, verschiedene Leitungsfunktionen bei Logistikdienstleistern, Absolvent Kompaktstudium Logistik an der Deutschen Logistikakademie in Bremen und zertifizierter Logistiker 'Senior-Level' nach den Standards der European Logistics Association, Ausbildung zum Speditionskaufmann, Jahrgang 1974

The impact of data aggregation on distribution planning: A case study

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Given the structure of a multi-level logistics network, distribution planning involves determining the flow of materials through the network so as to minimize total costs and meet service level requirements. Typically, large amounts of data are required to determine the best distribution strategy over a certain time horizon. These include, among others, locations of customers and network facilities, manufacturing and storage capacities, types of products, customer demands, warehousing costs, and transportation rates. In particular, when transportation is carried out by a third-party logistics provider, freight rates are charged based on weight classes and on the partition of countries into zones. This leads to the consideration of non-linear transportation costs, and thus adds to the complexity of an optimization model.

An essential step in distribution planning is the aggregation of data. We will explore various procedures ranging from customer aggregation to the approximation of non-linear transportation cost functions. We will illustrate the proposed strategies by means of a case study based on real data from a large manufacturer of ceramics. Our analysis will focus on the impact of the various strategies of replacing the original detailed data with aggregated data on solution quality and computational time.

Minimization of travel times and emissions for city logistics applications: Integration of large travel time databases in time-dependent and stochastic optimization approaches

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In recent years, GPS based travel time collection has led to large amounts of historical traffic data. These data are usually not fully exploited in city logistics applications such as shortest path computation and vehicle routing. Reasonable aggregation and integration of a large number of speed observations into well-known optimization approaches is challenging, but would lead to improvements with regard to travel times, routing costs, emissions, and service quality. This is especially important for metropolitan areas, where frequent changes of speed as often observed in peak times deteriorate emission rates significantly. Logistics service providers, however, usually determine paths according to distances or deterministic travel times, ignoring specifics of exhaust emissions.

In this talk, we discuss the determination of emissions optimized shortest paths in metropolitan areas. We present ideas of how to model CO_2 emissions based on empirical speed observations. Corresponding emission functions of speeds usually show a non-linear behavior, since relatively low as well as relatively high speeds are expected to result in larger amounts of CO_2 emissions than moderate speeds. A deterministic shortest path approach may not be sufficient, since high variation of speeds may be concealed by an average speed value, ignoring the unfavorable parts of emissions functions. From an emissions minimization point of view, it may be advantageous to choose a path with a longer distance, but more robust speeds. Thus, we compare deterministic shortest path computation to new variants of stochastic shortest path computation, minimizing emissions objectives.

For deterministic optimization, we consider time-dependent speed averages in order to derive time-dependent emission values. For stochastic optimization, the well-known Dijkstra's algorithm is extended so that large numbers of speed observations can be considered. The idea is to introduce time-dependent sampling of speed values in the estimation of arcs' emissions. Two variants of sampling are investigated that differ in complexity and computational efforts. For the arc-based variant, mean emissions for an arc are estimated based on the average of a fixed number of time-dependent speed samples. For the path-based variant, individual samples of each arc are propagated until the destination of the path is reached, providing a robust, emissions optimized path.

The quality of deterministic and stochastic shortest path approaches is investigated by computational experiments. We consider a real-world travel time data set of approximately 30 million travel time observations. Results of deterministic shortest path optimization are compared to the new sampling based variants. Emissions for all paths are evaluated using a simulation. Computational experiments show the superiority of deterministic emissions shortest paths over distance and travel time shortest paths. Sampling based approaches provide the best path recommendations from an emissions point of view, especially during rush hour periods.

Sales Force Deployment

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The sales force deployment problem arises in many selling organizations. This complex planning problem involves the concurrent resolution of four interrelated sub problems: sizing of the sales force, sales representatives locations, sales territory alignment, and sales resource allocation. The objective is to maximize the total profit. For this, a well-known and accepted concave sales response function is used. Unfortunately, literature is lacking approaches that provide valid upper bounds. Therefore, we propose a binary formulation with an infinite number of binary variables. The linear relaxation is solved by column generation where the variables with maximum reduced costs are obtained analytically. For the optimal objective function value of the linear relaxation an upper bound is provided. To obtain a very tight gap for the objective function value of the optimal integer solution we introduce a Branch-and-Price approach. Moreover, we propose exact contiguity constraints in order to ensure contiguous sales territories. In a series of computational studies we consider instances which may occur in the pharmaceutical industry. The largest instance comprises 50 potential locations and more than 500 sales coverage units. We are able to solve this instance in 1273 seconds with a gap of less than 0.01%.

Route planning for different time horizons

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Route planning is still quite a challenge from a theoretical, algorithmic and practical point of view. Having a lot of different algorithms at hand to solve problems with many different constraints, e. g. time windows, loading capacities, working time of employees, the theoretical description of a problem often is very diffuse.

The first problem arises when asking for a proper goal: In many discussions the minimization of costs can be found to be the quantity of interest. Even if we take this goal as appropriate for the realization, it often turns out to be unfeasible in practice. Searching for the optimal solution we try to find something like the minimum of the total cost. Practitioners often do only have quantities related to individual orders or some averaged values. Costs for a truck are often calculated using some averaged load and utilization. But, shipping two boxes from one source to one destination generates costs that range from the costs for one single box to the costs of two single boxes, depending on it, whether the two boxes are on the same truck or not. The total costs cannot be deduced seriously from the costs for one single order. To overcome this problem, we can use a very old fashioned ansatz that goes back to Paul Riebel from the 1960's, the *Grundsatz der entscheidungsrelevanten Kosten*. This says that we have take into account only those quantities that are affected by our decision. When looking for an optimal routing for one truck owned by the planner we have to consider the money that has to be spend for fuel, driver, wear and road charge but not the money invested – money spend for the total trip, or all trips, when many vehicles are considered. If the truck is rented, quantities of interest become different. Within a tactical horizon, i. e. when considering the structure and the size of the own fleet, the money needed for the investment necessarily has to be considered – but not on an operational level.

The second problem is due to switching between different temporal horizons from tactical planning over conventional order planning to operational control. Most realizations deal with the intermediate horizon, the conventional order planning: All orders and all vehicles that can be used, are known. The tactical and the operational level are considered much less.

One overall requirement should be that results for different horizons are consistent. The consistency of parameters throughout the entire process of planning and the lifetime of results is an absolute necessity.

Considering different temporal horizons, the crucial costs are different. With this change, different quality functions become necessary. Different, but not violating the requirement for consistency. Regarding the different interests of the involved actors, we get even more changes. Following the more realistic goal, maximizing the benefit instead of minimizing the costs, objective functions must be adapted further.

Having in mind the platitude that prices are determined by the market, the problem reveals even more unknowns: The price for shipping one box from Hamburg to München on Monday can be different to that on Tuesday. Maximizing the profit leads to an important simplification: We don't have to care about service levels or accepted levels of utilization. If a truck has a capacity of twenty boxes and the planner has to decide between one request with ten and another one with five boxes, he *simply* has to decide for the alternative with the maximum profit. To be able to do this, he needs the proper function for calculating the costs in the actual situation. On the operational level, the important goal is to fulfill all orders attached to vehicles. This restricts the number of possible solutions quite often to a very small number. More important on this level is the status of all trucks in transit. This status dominates the costs for performing incoming requests and the quality function must be different to those used before. Thinking of applications, where vehicles don't return to their home garage every evening, it would be helpful, to give an advice, where to go to after having finished the last stop for that day. Any application used for this operational level should incorporate a modul for forecasting the next days orders. The marketing and sales division have to be asked for the crucial data. Very valuable information can be obtained by observing and analyzing the actual characteristics of incoming requests and performed transportation tasks. The input of controlling is only important on a tactical level but not for planning and operation.

In this talk we will present a model that allows for considering the above mentioned aspects. Part of this modell is realized using heuristic opimization methods. We will present some results that reveal some typical consequences. Some of them are difficult to accept for practitioners: Waiting or doing nothing, i. e. leaving a truck unused in the garage, results sometimes in a higher profit than having all trucks distributed all over Europe driving all day. We will also present some results from a practical project.

Construction Heuristic for a Vehicle Routing Problem with Time-Dependent Functions

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Abstract The vehicle routing problem (VRP) has lots of diverse applications. This leads to numerous different planning attributes, constraints and optimisation goals in practice. An algorithm which addresses many real-world scenarios must be flexible and cannot rely on specialities some use cases might have while others don't. In contrast to project-specific solutions, a multipurpose software product is in need of such a general algorithm.

In the following, we outline a new construction heuristic for the VRP. Its main advantages are twofold: First, it works with time-dependent functions which enables us to better optimise for time issues in general. Second, its underlying model is flexible enough to cope with the input data of several different use cases. For instance, the use case "conveyance of passengers" differs heavily from "carriage of freight"; and in contrast to a daily planning horizon, vehicles usually do not return to the depot within a weekly planning horizon (e.g., transportation across Europe).

A construction heuristic is to find a good initial tour plan quickly. Usually, this plan would be improved by some metaheuristic later on, but this is out of our focus here. To this end, let a tour plan be a vector of chains, a chain be a vector of tours (one chain for each vehicle), and a tour be a vector of customers to be visited. Furthermore, let a time-dependent transition function u on pairs of customers be derived from the original input data. It is assumed that this function is piecewise-linear and it satisfies the FIFO property. For every point in time within the planning horizon, it represents the time it takes to go from one customer to another and perform some service of whatever kind there.

Crucial is the definition of a *merge*: For a tour, let its duration be the sum of transitions along the tour (plus the service duartion at the first customer). Then, the *merge tour* of two tours is a shortest tour (w.r.t. u, i.e., for every point in time) which visits the same customers and respects the relative order in the two original tours. A *merge chain* is defined similarly. If all u are constant, a merge can be computed using dynamic programming in quadratic time w.r.t. the sizes of the two original vectors.

Now, the algorithm roughly works as follows: Initially, place each customer in its own tour and calculate the merge tours for every tour pair, much like in the related Savings heuristic by Clarke und Wright. The main part of the algorithm has an outer and an inner loop: While some tour merge is possible, select a good merge tour T and calculate the merge chain of T and every chain (the parent tours of T need to be removed from their chains for this purpose). While some chain merge is possible, select a good chain merge. If it can be applied succesfully, calculate the merge tours of T with every other tour, and break out of the inner loop. So in a nutshell, there are four steps: {tour, chain} merge {selection, calculation}.

This procedure and its underlying model will be presented in more detail. We will also talk about how its flexibility and some enhancements (e.g., additional time-dependent cost functions on pairs of customers) can be used to cover diverse real-world cases. We currently started implementing our ideas and hope to be able to show some preliminary results.

Optimization approaches to the service network design of bike sharing systems

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In this contribution we present different optimization approaches to the service network design of bike sharing systems. Bike sharing systems have recently enabled sustainable means of mobility through unattended rental stations in metropolitan areas. When it comes to the operation of bike sharing systems, imbalances in the distribution of bikes affect the service quality, i.e., the provision of bikes and free bike racks. These imbalances are caused by spatio-temporal variation of bike rentals following typical traffic flows in the course of day and week. Furthermore, the flexibility of BSS fosters one-way rentals, intensifying imbalances in the distribution of bikes. Due to limited capacity at stations, rentals are impossible at empty stations, and returns are impossible at full stations.

In order to increase the service quality, bike imbalances can be handled by means of strategic, tactical or operational planning. On the strategic level, the size of stations needs to be set. On the tactical level, the initial allocation of bikes needs to be determined in order to compensate varying bike demand in the course of day. On the operational level, relocation of bikes from rather full to rather empty stations maintains a certain level of service quality. Planning decisions are interdependent: Reasonable sizing of stations and allocation of bikes may reduce relocation efforts, whereas high relocation efforts may compensate insufficient sizing and bike allocation.

We propose an integrated approach in order to optimize the service network design of BSS. The presented service network design models determine (1) the optimal size of stations, (2) the optimal initial bike allocation at stations, and (3) the expected costs of relocation while ensuring a certain service level. Optimization balances between investment in service network infrastructure, i.e., bikes and bike racks, and enduring costs resulting from manual relocation of bikes in daily service operations.

In particular, we discuss three approaches to the modeling of relocation: a deterministic linear program (DLP), a deterministic mixed-integer program (DMIP) and a stochastic linear program (SLP). The DLP neglects restrictions on the frequency and volume of relocation, but is computationally fast. The DMIP anticipates lot sizes by facilitating pooling of bikes, but is computationally intractable for big instances. Both deterministic approaches rely on the average rental demand. On the contrary, the SLP yields a robust solution taking different demand scenarios into account. The proposed approaches are exemplified based on two years of bike trip data from Viennas 'Citybike Wien'.

Models and Algorithms for Considering Vehicle Scheduling Constraints in Timetable Synchronization Problems.

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It is a common problem of public transport associations that the timetables of the different public transport companies are ill-synchronized. This is often revealed only shortly before the timetable is published. Considering this situation, it is not possible to modify the timetables significantly, anymore. However, it may be feasible to shift individual tours or sets of tours by some minutes in order to optimize the average transfer quality for the customers.

However, one may not neglect the effects that the modifications will have on the feasibility of the present vehicle schedules. We will discuss models that integrate the transfer optimization problem with the vehicle schedule problem. We will give theoretical results, as well as demonstrate our experiences with real-world data.

New Approaches to territory planning

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Territory planning is the problem of grouping small geographic areas (so called basic areas) into larger geographic clusters (so called territories or districts) in a way that the latter are acceptable to relevant planning criteria. Typical examples for basic areas are counties, zip code areas, streets or adresses of costumers. Territory design problems treated by operations researchers are motivated by quite different applications ranging from political districting to sales and service territory design. Typical planning criteria are balance, compactness, and contiguity. Balance describes the requirement for territories to have approximately the same size, in terms of workload, number of customers, or voters. A territory is said to be geographically compact if it is more or less round-shaped and undistorted. Compact territories usually reduce the sales person's unproductive travel time. Contiguity is required for administrative reasons or, like compactness, to reduce unnecessary travel.

In this talk we will first review several typical applications for territory design problems and try to identify essential elements, common to all applications. Afterwards a short overview of models and solution techniques found in the literature for solving districting problems will be given. We will then focus on a method for solving the problem, which is based on ideas from the field of computational geometry.

In the last part of the talk we will address practical problems in the context of sales territory design. In this case, the locations of the sales persons are often given in advance. Therefore, the territories have to be designed in a way that the territory of a sales person is around his location, or respectively as close as possible to his location. Furthermore, in contrast to classical territory design problem, there is a greater focus on the routing within the territory: The travelling time is a significant part of the working time and constraints like time windows or frequency of visits have to be considered.

Load balancing and equilibria for site-dependent vehicle routing problems

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Consider the Site-Dependent Vehicle Routing Problem (SDVRP), i.e., each demand node establishes a set of feasible vehicles that are allowed to serve that node. A particular SDVRP is the Skill VRP where a vehicle is allowed to serve a node if the vehicle's skill meets the skill requirement of the node. The site-dependencies as well as the skill requirements lead to a heterogeneous set of vehicles. This heterogeneity in turn might lead to imbalanced situations. For instance, Skill VRP solutions show a tendency to have a bad load balancing and resource utilization. In a majority of solutions only a subset of vehicles is utilized while the remaining vehicles are inactive. Moreover, a considerable share of demand nodes is served by vehicles that have a skill higher than necessary, i.e., skill resources are not utilized properly.

In this talk, we discuss two research directions to address the imbalance among players in the SDVRP and the Skill VRP. First we propose model modifications in order to improve the load balancing and the skill utilization. In particular, we study a minmax approach that aims at minimizing the maximal vehicle tour length as well as a combination of the minmax approach and a distance constrained Skill VRP.

Second, we study the behavior of the vehicles if they act as players in a noncooperative n-person game. To this end we propose the Vehicle Pricing Game (VPG). In the VPG, each vehicle demands a price per km for carrying out a tour. Based on these prices, a VRP is solved under the objective of minimizing the total routing costs. Given that the profit of a vehicle depends on the length of the assigned tour as well as on the demanded price, we address the question which price a vehicle should choose to maximize the own profit, taking into account the competition among the vehicles.

Scheduling Drivers' Breaks and Rests under Additional Time Constraints

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In the Vehicle Routing Problem with Time Windows (VRPTW), drivers have to visit customers to perform services which can only start in given time intervals. The subproblem of computing the duration of a single route is not difficult to solve, but if the law stipulates a number of breaks and rests for the driver, the problem of finding a legal schedule for his route may become complex.

For truck drivers, the European Union has laid down multifaceted regulations regarding mandatory breaks and rests. We aim at finding an (optimal) schedule for the driver that is also compliant with these regulations. Due to the complexity of this problem, we studied it on its own. Since this subproblem needs to be solved very frequently within VRPTW algorithms, the runtime of the corresponding subroutine is of major importance.

We present an efficient and flexible algorithm that not only covers the EU drivers regulation but also takes regulations on working hours and different other temporal constraints into account. Our implementation of the algorithm is able to find high quality time schedules in less than one millisecond for real world instances.

Problem Definition We want to find a legal time schedule that observes the restrictions described below. The objective is to optimise first for earliest arrival time and then for shortest tour duration (lexicographically).

We are given a list of customers in a fixed order and driving times between consecutive customers. Each customer has an associated service period and a list of service intervals. Service is only allowed to start within service intervals. It is given whether the driver can recreate (*passive service*) or has to work during service (*active service*). A list of operating intervals is given to specify periods in which driving and active service is allowed (e.g., to model driver availabilities).

The regulation of the European Union restricts driving times and demands specific recreation periods. In the following, we summarize the most important features of the regulation:

A break of 45 minutes (splittable into 15 + 30 minutes) has to be taken after 4.5 hours of driving.Daily driving shall not exceed 9 hours, but can be extended at most twice a week to 10 hours. Daily rests of at least 11 hours (splittable into 3 + 9 hours) and weekly rests of at least 45 hours must be taken. At most thrice between two weekly rests, the driver may reduce the daily rest period to 9 hours. Weekly driving time shall not exceed 56 hours; driving time accumulated in two consecutive weeks shall not exceed 90 hours. Similar obligations come from the social legislation for working hours. We consider them as well but omit the details here.

Algorithm Description Our method is based on the A* search heuristic. Nodes in the search tree represent a partially computed schedule. Edges represent actions of a specified duration (e.g., driving for 30 minutes). The search tree is constructed at runtime by a branching mechanism which evaluates the current node and determines follow-up actions.

Our implementation is modular as several rules are independent of each other. We implemented future-cost-heuristics for multiple rules and use the maximum of it as the estimate. A speed-up-heuristic within the branching mechanism may reduce the number of actions. A tuning parameter allows a trade-off between solution quality and runtime. We do not use any dominance criterion.

Results and Conclusion We developed an algorithm that can be used efficiently as a routine within VRPTW algorithms. Its runtime mainly depends on the number of explored nodes during search. We obtain very small search spaces for most instances.

We give some performance data measured on a desktop computer (Intel Core2 Duo, 3 GHz, 4 GB RAM). We observe the worst performance for large randomly generated instances. With around 20 customers and many service intervals, computations take few milliseconds on average. Real world instances behave better. With around 30 customers but only few service intervals per customer, a search takes far less than one millisecond.

There are still open challenges we want to tackle. In particular, the extension of our approach to time dependent driving times is of interest.

Modern Routing Algorithms in Practice

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In the last few years there has been a lot of research on routing algorithms solving the shortest path problem in road networks. With a certain amount of preprocessing the new methods allow to solve shortest path queries by several orders of magnitude faster than Dijkstra's algorithm.

In addition to solving a plain shortest path problem in a road graph where nodes are crossings and edges are road segments with travel time as cost, a routing algorithm for practical route or tour planning has to fulfill further requirements. For example, some turns are not allowed or, more general, turn costs have to be applied. Another crucial point is the optimization criterion for the routes: several criteria such as distance, travel time, or toll price are involved, and some of the criteria are even time-dependent.

In the talk a short overview of the recent developments is given, with a special focus on calculating distance matrices as input for vehicle routing problems. Some examples will show that for many practical use-cases there are already efficient techniques available, but there are still open problems and drawbacks of existing techniques. Finally, preliminary results of an ongoing study on integrating toll prices into a routing algorithm will be presented.

Welche Herausforderungen sind bei Produkteinführungen von Tourenplanungs-software zu meistern?

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Bei der Erstellung und Einführung von Standard-Software zur Tourenplanung muss eine Vielzahl von Anforderungen, Einflussfaktoren und Funktionsbereichen berücksichtigt und beherrscht werden. Nur so entsteht die notwendige Akzeptanz bei Kunden und Benutzern und damit ein erfolgreiches Tourenpla-nungsprodukt. Die neben der eigentlichen Kernfunktionalitt, der auf Algorithmen basierenden Planung und Optimierung wichtigsten Prozesse und Funktionen werden im Vortrag vorgestellt. Abbildung von planungsrelevanten Daten und deren Aufbereitung Kompensation von Defiziten in der Daten und Prozessmodellierung der Kun-den Integration von Daten und Prozessen, Schnittstellen Modellierung von Planungsaufgaben und Abbildung von Transportprozessen Usability, Nachvollziehbarkeit, Erwartungskonformität Transportlogistik relevante Regulierungen und Vorschriften berücksichtigen und deren Einhaltung unterstützen oder sicherstellen