Report from Dagstuhl Seminar 16171

Algorithmic Methods for Optimization in Public Transport

Edited by

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Abstract

This report documents the talks and discussions at the Dagstuhl seminar 16171 "Algorithmic Methods for Optimization in Public Transport". The seminar brought together researchers from algorithm, algorithm engineering, operations research, mathematical optimization and engineering, all interested in algorithms in public transportation. Also several practitioners were able to join the group and brought valuable insights on current practice and challenging problems.

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1 Executive Summary

Leo G. Kroon
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Public transport systems are highly complex systems, due to their technical and organizational complexity, and due to the large numbers of passengers that are transported each day. The quality of the services provided to the passengers is on the one hand the result of the quality and robustness of the underlying plans, such as the timetable and the vehicle and crew schedules. On the other hand, in real-time the quality of the service is the result of the complex interactions between the real-time logistic management of the public transport system and the information to and guidance of the passengers.

Both in the planning stage and in real-time, dealing with these problems requires handling large amounts of data, solving complex combinatorial optimization problems, and dealing with uncertainty. Preferably, the optimization models aim to improve the robustness of the public transport system, so that the system is less vulnerable to disturbances.

In addition, due to the use of smart cards and smart phones, it becomes technically possible to give personalized real-time traffic advice for passengers to guide them to their destinations, even in disturbed situations. In addition, the use of these devices makes huge amount of data available, which can improve decisions in real-time control and in disruption management as well as in the planning stage.

In this seminar, researchers from algorithm engineering and operations research worked together with researchers with an engineering background and participants from practice. The common goal was to improve methods for planning and scheduling of public transportation.

Among others, some specific topic which were covered were

- *Scheduling* of public transport. Several new applications and new ideas on algorithms for public transport scheduling were presented.
- *Integration of planning stages.* Suggestions were developed on how the traditional approach of sequential planning can be replaced by integrated approaches.
- *Robustness and recoverability.* Here several talks discussed methods on how to react to different kinds of disturbances, or how to make schedules more robust.
- *Real-time control.* Real-time control measures which can be taken to get back to the plan as soon as possible were proposed and discussed.
- *Routing in public transport.* For the important issue of routing passengers in public transport, also needed for timetable information systems, several algorithms and new approaches were presented and discussed.
- *Applications and case studies.* Among others the situation in Mumbai, India, was presented and discussed and representatives of several public transport operators sketched the planning process in their companies and pointed out open questions for further research.
- *Future technologies* were another important issue. The participants discussed the potential of new technologies and identified algorithmic challenges for their future utilization.

The seminar started with an introductory round in which every participant presented him- or herself with three slides. It was a good start to get to know each other. In the following days, nearly all participants contributed with talks. There were also two panel discussions, one with the other Dagstuhl group on learning algorithms, and another one on future technologies. The participants discussed and identified challenging algorithmic problems in this field.

Finally, the organizers would like to thank the Dagstuhl team and all the participants for a fruitful and successful seminar.

Leo Kroon, the main organizer of this Dagstuhl seminar, died unexpectedly on 14 September 2016. We are shocked and very sad about his sudden death. Leo was a great scientist and a wonderful person. We will never forget him.

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3 Overview of Talks

3.1 Integrated Public Transport Optimisation and Planning

Allan Larsen (Technical University of Denmark – Lyngby, DK)

Joint work of Stefan Ropke, Roberto Roberti, Evelien van der Hurk, Joao Fonseca, Allan Larsen

The planning of efficient and cost-effective public transport systems offering high-class service to the users is a very complex task. The Integrated Public Transport Optimisation and Planning (IPTOP) research project aims at developing new methods for planning, designing, controlling and optimising Danish public transport systems. The IPTOP project financed by the Strategic Research Council of Denmark spans over a five year period and has just entered into its second year. In this presentation I will provide an overview of the overall project aims as well as introduce our current efforts of integrating some of subproblems of the planning process into optimisation models. These works include a project on integration of bus timetabling with vehicle scheduling and another project on integration of train timetabling and rolling stock planning.

3.2 Hypergraphs in traffic optimization

Ralf Borndörfer (Konrad-Zuse-Zentrum – Berlin, DE)

Joint work of Marika Karbstein, Isabel Beckenbach, Olga Heismann, Markus Reuther, Thomas Schlechte, Christof Schulz, Steffen Weider, Ralf Borndörfer
URL http://www.zib.de/projects/service-design-public-transport
URL http://www.zib.de/projects/modal-raillab

Traffic optimization is intimately related to algorithmic graph theory, which provides elegant solutions to problems ranging from network design to vehicle rotation planning. Extending these approaches to a hypergraph setting is a natural next step that allows to deal, in a mathematically appealing way, with complex types of constraints beyond the node-edge level. The talk illustrates the potential of hypergraph models on two examples in line planning and railway vehicle rotation planning. Line planning gives rise to the Steiner path connectivity problem, a generalization of the Steiner tree problems to hypergraphs, while railway vehicle rotation planning leads to the consideration of hyperassignment problems. These models, their theory, and algorithmic solution will be discussed.

3.3 Timetable Planning of a High-Speed Chinese Railway Corridor

Valentina Cacchiani (University of Bologna, IT)

Joint work of Feng Jiang, Paolo Toth, Valentina Cacchiani

In this work, we consider the Train Timetabling Problem (TTP) in the planning phase, which calls for determining an optimal schedule for a given set of trains, while satisfying several constraints related to safety and to the physical infrastructure. In particular, we focus on the TTP of the high-speed trains of the Chinese Beijing-Shanghai corridor. Two are the objectives to be achieved, namely scheduling as many trains as possible and obtaining a regular schedule, i.e. a schedule showing regularity in the train frequency at the main stations. We present a Lagrangian-based heuristic algorithm adapted from a previous work to deal with new objectives and constraints. In addition, we present our research ideas on this problem and on the general TTP.

3.4 Railway traffic control targeting passenger flows

Francesco Corman (TU Delft, NL)

Joint work of Dario Pacciarelli, Alessio D. Marra, Andrea D'Ariano, Marcella Samà, Francesco Corman
Main reference F. Corman, A. D'Ariano, A. D. Marra, D. Pacciarelli, M. Samà, "Integrating train scheduling and delay management in real-time railway traffic control," Transportation Research Part E: Logistics and Transportation Review, 2016.
URL http://dx.doi.org10.1016/j.tre.2016.04.007

Optimization models for railway traffic rescheduling tackle the problem of determining, in real-time, control actions reducing effect of disturbances in railway systems. In this field, mainly two research streams can be identified. On the one hand, train scheduling models are designed to include all conditions relevant to feasible and efficient operation of rail services, from the viewpoint of operations managers. On the other hand, delay management models focus on the impact of rescheduling decisions on the quality of service perceived by the passengers. Models in the first stream are mainly microscopic, while models in the second stream are mainly macroscopic. This paper aims at merging these two streams of research by developing microscopic passenger-centric models, solution algorithms and lower bounds. Several fast heuristic methods are proposed, based on alternative decompositions of the model. A lower bound is proposed, consisting of the resolution of a set of min-cost flow problems with activation constraints. Computational experiments, based on multiple test cases of the real-world Dutch railway network, show that good quality solutions and lower bounds can be found within a limited computation time.

3.5 Industrial issues for Mass Transit Operations

David De Almeida (SNCF – Paris, FR)

This talk will focus on public transport systems in their Mass Transit version and will be illustrated with the context of the Paris region. It will underline the major role of heavy rail, together with other multimodal complements. After reviewing some facts about the volume of customers (in signicant growth those last 10 years) and trains that need to be matched, some issues related to the transport capacity and customers service quality will be discussed. The talk will also illustrate short to long term opportunities for decision-making and OR models from the point of view of the Innovation & Research Division of SNCF. In particular, we will underline needs for research and approaches enhancing operation monitoring, disturbance early detection and real-time decision aid. Models for integrating the planning and real-time management of operations in complex local areas (like major stations where timetabling, platforming and shunting problems must be simulateously dealt with) will also be discussed. We will finally share some thoughts about requirements (data access, human factors...) that need to be adressed in order to leverage the actual use of such works in railway companies.

3.6 Challenges in Public Transport and in Public Transport Planning

Markus Friedrich (Universität Stuttgart, DE)

The presentation summarizes various challenges public transport may face in the coming decades.

1. Demand side challenges.
   Will demand for public transport increase or decrease? Fewer younger people and a higher share of wealthy elderly may increase car ownership and may lead to less demand for public transport in urban areas. Young adults which seem to be more open to sharing concepts may increase demand for public transport. As expanding companies more and more move out of cities the share of public transport for work related trips may decrease. Forecasts for the German Transport Master Plan indicate that local public transport will increase less than car transport and long distance public transport.
2. Supply side challenges.
   Can public transport compete with the car? Currently the mode car serves 80% of of all person-kilometres travelled in Germany. One reason for this is simply that car is faster. Advantages of public transport result from lower travel costs, from shorter travel times to dense urban centres during peak hours and from the possibility to use the travel time for reading or other activities. The next generation of cars will consume less energy, will produce fewer local emissions, will be more comfortable and always connected, will assist the driver, will drive partly autonomously and park autonomously. This will lead to higher traffic safety and more benefits for car-users as they can perform other activities during their journey. As a consequence, it is likely that public transport will lose travellers to public transport. If society does not like this development, transport policy should introduce road pricing schemes and use the revenues to improve public transport.
3. Challenges in planning.
   What are obstacles in public transport planning? Major obstacles result from the fact that transport planning (planning of stops, line routes and headways) and operation planning (timetable planning, vehicle and driver scheduling) are not integrated.
4. Challenges in operation.
   How can we handle disturbances?
   Public transport networks are more vulnerable to network disturbances than car networks. Providing redundancy is expensive. For the daily operation standard fleet management systems still provide little support for handling disturbances. To overcome these shortcomings, it is necessary to develop and implement methods for better forecasting the downstream travel times of public transport vehicles. Better vehicle dispatching systems should support dispatchers by suggesting suitable measures.

5. Challenges in financing.
   How can we finance future public transport?
   In urban public transport in Germany passengers pay roughly 1€/trip or 2€/day. Electronic ticketing still is very basic and not customer friendly. Best pricing options are not available. Bus drivers earn approx. 15€/h, need to work extra hours to feed a family, are hard to find in some areas and therefore should not be the main source when minimizing costs. Cost coverage of operating costs (labour, rolling stock, fuel) lies between 50% to 70%. Additional supply usually increases the deficit. Introduction of smaller vehicles can provide more economic solutions than stand vehicle sizes. As small vehicles also require drivers they can never provide competitive prices and require high subsidies per traveller. This may change with self-driving busses, which will probably be only available after the self-driving car. Financing local public transport will therefore continue to require public subsidies. The can be justified by the positive impacts of public transport to society. Public transport reduces congestion, provides travel opportunities for everybody and is more environmental friendly than cars.
6. Conclusion.
   Public Transport is great as it provides mobility options to everybody, avoids auto-dependency, is the best ride-sharing system available, is the only system which can provide high capacity transport for metropolitan areas even with self-driving cars, needs less energy per person kilometres than other modes, if occupancy rate is > 40%. Public Transport has shortcomings as it is only faster than car in case of high speed trains or in congested urban areas, does often not offer competitive prices, is less comfortable than a car, is often not reliable and requires subsidies, which must be justified.

3.7 Public Transport in Emergency Planning

Marc Goerigk (Lancaster University, GB)

Thinking of an emergency evacuation, pictures that come first to our mind would be cars stuck in long queues, or masses of pedestrians. However, public transport plays its important, but relatively little known part in emergency planning. The purpose of this talk is to give an overview of the applications and research fields involved, to promote a closer collaboration between the two research communities, and to point out current research questions.

3.8 Dealing with uncertainty in railway traffic management and disruption management

Rob Goverde (TU Delft, NL)

Uncertainty is an essential part of railway operations. In disruption management the durations of disruptions is uncertain and estimations typically have large variance. Likewise, in traffic management conflict predictions have some uncertainty although with less variance. How to deal with this uncertainty to get high performance of operations control? This is the focus of this talk.

3.9 Further Insight into Single Track Train Scheduling

Jonas Harbering (Universität Göttingen, DE)

Joint work of Jonas Harbering, Abhiram Ranade, Marie Schmidt, Oliver Sinnen

In this talk we present the single track train scheduling problem. The idea for studying this problem was raised by the current situation of public transportation in India. Large parts of the infrastructure network are composed of single track stretches and the aim is to use the given capacitated infrastructure as good as possible.

In the single track train scheduling problem a linear network is given. While the capacity of the track segments is one, meaning between two consecutive stations there can only be one train at any given time, the capacity of the stations is unlimited. A set of trains from the left hand side and a set of trains from the right hand side are given which are to traverse the entire network towards the right hand side and left hand side, respectively. The aim is to minimize the makespan, i.e., the time from the first departure of the first train until the last arrival of the last train.

Some results on polynomial and weakly polynomial time algorithms for instances with only four stations are shown to solve the problem. Furthermore, a dynamic programming algorithm is shown to have a pseudo-polynomial runtime, given that the number of stations is fixed. Finally, extensions for this problem leading to more realistic settings are discussed.

References

1 J. Harbering, A. Ranade, M. Schmidt, O. Sinnen *Single Track Train Scheduling*. Preprint-Reihe, Institut für Numerische und Angewandte Mathematik, Georg-August Universität Göttingen

3.10 Hyperpaths for Public Transport Assignment

Mark Hickman (The University of Queensland, AU)

Passenger assignment involves determining passenger flows in a public transit network. These assignment models are typically associated with individual passenger behaviors, such as a “strategy” among attractive lines at a stop or a discrete choice among scheduled services. In these cases, assignment can be described using hyperpaths. From empirical data, such hyperpaths can be observed in practice. However, identifying these hyperpaths is computationally challenging, and calibrating passenger behavioral models is similarly complex. These challenges are discussed, along with both algorithmic successes and limitations for these hyperpaths.

3.11 Computing and Improving Passenger Punctuality

Dennis Huisman (Erasmus University – Rotterdam, NL)

In this talk, we present new key performance indicators (KPIs) on passenger punctuality. These KPIs are part of the contract between the Dutch government on one side, and NS and ProRail on the other side.

In the presentation, we will explain how the KPIs are computed. Moreover, we would like to have an discussion on ideas how these KPIs can be improved.

3.12 Smart Route Planning for Public Transit

Giuseppe F. Italiano (University of Rome "Tor Vergata", IT)

Joint work of Luca Allulli, Donatella Firmani, Luigi Laura, Federico Santaroni, Giuseppe F. Italiano

Current journey planners for public transport are mostly based on timetabling information only, i.e., they hinge on the assumption that all transit vehicles run on schedule. Unfortunately, this might not always be realistic, as unpredictable delays may occur quite often in practice. In this case, it seems quite natural to ask whether the availability of real-time updates on the geo-location of transit vehicles may help improving the quality of the solutions offered by routing algorithms. To address this question, we considered the public transport network of the metropolitan area of Rome, where delays are not rare events, and reported the results of our experiments with two journey planners that are widely used for this city: one based on timetabling information only (Google Transit) and one which makes explicit use of GPS data on the geo-location of transit vehicles (Muovi Roma).

3.13 Robust Efficiency for Resource Scheduling: Insights from Public Bus Transport and Airline Cases

Natalia Kliewer (FU Berlin, DE)

Joint work of Natalia Kliewer, Bastian Amberg, Lucian Ionescu

We analyze and compare robust efficiency of resource schedules in public bus transportation and airline industry, both dealing with the competing objectives of cost-efficiency and schedule robustness under delays. Generalizing the findings from robust and efficient vehicle and crew scheduling in both airline and public transport contexts, we compare different techniques that lead to an improvement of the non-dominated solution front.

3.14 Challenges for Public Transport

Leo G. Kroon (Erasmus University – Rotterdam, NL)

We describe several challenges for the further improvement of public transport systems. These challenges are partially related to further improving the current supply-oriented public transport systems as they are currently, usually based on a fixed line system and timetable. As has been described in other abstracts, these challenges are in the following areas: passenger orientation, integration of planning stages, robustness and resilience, energy efficiency, and disruption management. Another challenge is to effectively use the wealth of big data that is available nowadays to improve the quality of public transport systems. The challenges are also partially related to future demand oriented public transport systems that may be operated in a number of years from now. These systems may be operated with electrical autonomous cars, and provide more personalized public transport. Challenges in this area may be related to determining how many vehicles are needed to operate the system at a certain service level, which dispatching and routing strategies to use in real-time for routing the vehicles, how to route the passengers through the system, which charging strategies to use to guarantee that the vehicles do not run out of power, and which pricing strategies to use to manage the passenger demand? Such questions provide an interesting new research agenda for the public transport research community.

3.15 Integrating Passenger Assigment and Timetabling for Capacitated Public Transit Networks

Marco Laumanns (IBM Research Zurich, CH)

Joint work of Marco Laumanns, Jacint Szabo, Maya Voegeli

In this talk we present a bilevel optimization model for the integration of passenger assignment into the (periodic) timetabling problem for capacitated public transportation networks. For the lower level problem we present a mixed-integer problem formulation which is based on the assumption that passengers are daily commuters with perfect information and which takes into account selfish routing and prioritization of already on-board passengers over boarding passengers. The integration of this problem formulation into the timetabling problem results in a mixed-integer bilinear programming problem. In order to solve this problem we propose a heuristic solution approach for general instances. Additionally, we present a direct approach which is obtained by a mixed-integer linear program reformulation using unary or binary expansion and McCormick relaxation. To improve the performance of the direct approach we provide problem-specific cutting planes as well as a reduction of the number of binary variables motivated by analysis of the problem structure.

3.16 Real-time Re-scheduling for Public Transit

Janny Leung (The Chinese University of Hong Kong, HK)

Joint work of KUO Yong-Hong, LAI Shuwo David, CHEUNG Kam Fung Henry
Main reference J. M. Y. Leung, D. S. W. Lai, Y.-H. Kuo, H. K. F. Cheung, "Real-Time Integrated Re-scheduling for Public Transit", in Proc. of the Third Int'l Conf. on Railway Technology: Research, Development and Maintenance, Civil-Comp Press, 2016.
URL http://dx.doi.org/10.4203/ccp.110.287

We study a vehicle and crew (re-)scheduling problem for a public transit system which is subject to highly stochastic travel times and disruptions. Our research is motivated by the operations of the tramways system in Hong Kong, which serves hundreds of thousands of passengers per day in a densely populated area and whose operations face severe challenges because it does not run on dedicated tracks but must share the road with vehicular traffic in heavily congested areas.

We investigate how the availability of historical and real-time location and traffic information can be exploited to provide decision support to the controllers. We develop a model for the re-scheduling of vehicles and crew, so as to maximize the route frequencies in order to provide good service to passengers, and minimize the violation of staff regulations (meal-break delays and overtime) taking stochastic time-dependent travel-time uncertainties into account.

In the operations that motivated our research, re-assignment of motormen/trams to different routes is possible only upon arrival at a terminal. Therefore, our decision support system is a "look-ahead" model (solved repeatedly on a rolling horizon basis) to find the best set of re-assignments for all trams and motormen that will be arriving at some terminal within the next time period. For all trams arriving at a terminal within the planning period, we consider all possible subsequent schedules that could be assigned to the tram and evaluate the cost (in terms of overtime, demand coverage, meal-break delays, etc.). Using a matching-based model, re-assignment of routes for all trams arriving at the terminals within the planning period is optimised.

We also explored a variant of the model where we consider demand constraints not only for the current planning period, but also several time periods into the future. Another variant of the model considers crew and tram availability. Yet another variant is the incorporation of planned maintenance of the vehicles into the daily scheduling. We are also interested in exploring the robustness of the model when the frequency of re-optimisation is increased. Future research will investigate how real-time demand information (from multi-media sources) might be available and how the system can operate to be more demand-responsive dynamically.

3.17 Integrated railway operations planning: What we can do and how?

Lingyun Meng (Beijing Jiaotong University, CN)

There is a trend that we integrate railway operations planning processes to get better solutions. This talk gives questions regarding necissity of integration, possible interesting and valuable integration related topics, challenges and potential methods to deal with them. Also we report our ongoing work with regard to demand-oriented vehicle routing scheduling for a transport system and integrated railway traffic control and train control.

3.18 A non-compact formulation for job-shop scheduling problems in transportation

Carlo Mannino (SINTEF ICT – Oslo, NO)

Joint work of Leonardo Lamorgese, Carlo Mannino

A central problem in transportation is that of routing and scheduling the movements of vehicles so as to minimize the cost of the schedule. It arises, for instance, in timetabling, dispatching, delay and disruption management, runway scheduling, and many more. For fixed routing, the problem boils down to finding a minimum cost conflict-free schedule, i.e. a schedule where potential conflicts are prevented by a correct timing of the vehicles on the shared resources. A classical mathematical representation involves continuous variables representing times, (time-precedence) linear constraints associated with single vehicles, and disjunctive (precedence) linear constraints associated with pairs vehicles. There are two standard ways to linearize disjunctions, namely by means of Big_M formulations or by time-indexed formulations. Big_M formulations tend to return notoriously weak relaxations, whereas time-indexed formulations quickly become too large for instances of some practical interest. In this work we develop a new, non-compact formulation for such disjunctive programs with convex piece-wise linear cost, and solve the resulting problems by row-generation. Our initial tests show that the new approach favourably compares with the so-far most effective approach on a large number of real-life test instances from railway traffic management. Moreover, it opens up for several research directions, ranging from investigating polyhedral properties to algorithmic speed-ups.

3.19 A convex programming approach for stochastic timetable optimisation

Gabor Maroti (VU University Amsterdam, NL)

The punctuality of the trains has always been one of the most scrutinised, and often ridiculed, performance indicators of a railway network. Recent research has proposed various optimisation model for improving the delay absorption capacity of a timetable.

Kroon et al. [1] described a stochastic programming model. While the model has shown its value in practice, the solution approach does not scale well, and becomes barely tractable for practically interesting instances.

In this talk we propose a convex programming solution approach for the model of Kroon et al. [1]. It turns out that our algorithm solve large real-life instances very quickly and reliably, with tight optimality guarantees.

One can argue, though, that we are solving the wrong problem. We optimise the train delays and not the passenger delays. The next challenge is thus to understand to way how passenger delays arise from train delays, and to incorporate this effect in the timetable optimisation algorithm.

References

1 L. G. Kroon, G. Maroti, M. Retel Helmrich, M. J. C. M. Vromans, and R. Dekker. Stochastic improvement of cyclic railway timetables. Transportation Research Part B, 42(6):553–570, 2008.

3.20 Objectives in Rapid Transit Network Design and Line Planning

Juan Antonio Mesa (University of Sevilla, ES) and Francisco A. Ortega

Planning rapid transit systems includes decisions about the design of the lines as well as frequency and capacity of the service. These decisions seek a trade-off between supply and demand. There are two main kinds of agents interested in the network design and line planning process: travelers and construction and operating companies. Moreover, local, regional or state authorities represented by the transportation agency are also a part. The general aim of a rapid transit system is to improve the mobility of citizens. One of the aims of the authorities is to facilitate the accessibility to rapid transit and to maximize the coverage. Travelers want to have the possibility of traveling at any time, as fast and as cheaply as possible, and without transfers. Companies want to minimize construction, vehicle, and operating costs, and maximize revenue. Therefore, there are many functions to be applied as objectives in network design and line planning. Among design variables are node and edge selection, frequency and capacity of the trains. Most of the scientific literature is dedicated to studying a particular problem with one objective function. However, several questions arise when dealing with a real-life problem: which is the measure to be used as objective. function? Are there analytical or experimental relationships between identical problems with different objective functions? How to weigh linear combinations of different measures? What about globalizing function and multicriteria approaches? Although most of the problems are NP-hard, are there significant differences in computational times? In this talk an overview of the scientific challenges that presents this kind of problems has been presented.

References

1 David Canca, Alicia de-Los-Santos, Gilbert Laporte, Juan A. Mesa *A general rapid transit network design, line planning and fleet investment integrated model*. Annals of Operations Research, DOI 10.1007/s10479-014-1725.0, 2014.
2 R. van Nes, P.H.L. Bovy *Importance of Objectives in Urban Transit-Network Design*. Transportation Research Record 1735, 25–34, 2000.
3 Sutapa Samanta, Manoj K. Jha *Modeling a rail transit alignment considering different objective* Transportation Research, Part A, 45, 31–45, 2011.
4 Anita Schöbel *Line Planning in Public Transportation: Models and Methods* OR Spectrum, 34, 491–510, 2012.

3.21 Robust Routing in Urban Public Transportation: Evaluating Strategies that Learn From the Past

Matus Mihalak (Maastricht University, NL)

Trams and buses of an urban transportation do not always run according to the timetable, because of unavoidable delays. Using journeys planned according to the timetable may be sub-optimal, if a carefully planned transfer fails because of a late arrival at the transfer bus stop. Robust routing aims at providing journeys in an urban transportation network that are (somewhat) resilient against delays. In this talk I present an approach to robust routing that learns from the past. In particular, we have access to the exact travel times of each of the vehicles in the system over the few past days, say, of the last 2-3 weeks. For every day, these travel times define a so-called recorded timetable (a timetable for which the buses and trams were not delayed on that day). We concretely investigate the following optimization problem: Given a target time T, an origin stop O and a destination stop D, what is the time-optimal journey that takes me from stop O to stop D on time, i.e., before time T?

We investigate several heuristics for this robust routing question: (1) we adapt the min max relative regret approach that takes 2,3, or 7 past days as the reference set of instances (recorded timetables) for which we want to find a good journey, (2) we find a journey J that minimizes AVG(J) + alpha*DEVIATION(J), where AVG(J) is the average travel time of journey J over the recorded timetables, DEVIATION(J) is the standard deviation of journey J, and alpha is a parameter (that can be tuned), (3) we compute an optimal journey that allows at least T minutes for transfer between two bus/tram lines. We use some of the recorded timetables for learning purposes, and some for testing. Our experimental results show that the approach (2) gives superior results. The approach, however, needs a fine tuning of alpha according to the recorded timetables. On the other hand, approach (1) does not require any fine-tuning at all, and is in every aspect very competitive with approach (2). Finally, we observe that approach (3) fails by far to compete with (1) and (2).

3.22 MIDAS-CPS: A Possible Future of Proactive Traffic Management Systems

Pitu Mirchandani (Arizona State University – Tempe, US)

While driving on your favorite route to your destination, have you ever wondered why the technology you are seeing as far as traffic management is concerned is so antiquated? My answer to that is the people and organization that manage the traffic are not “cyber-physicists” nor “real-time optimizers”. MIDAS hopes to demonstrate the synergistic use of a cyber-physical infrastructure consisting of smart-phone type devices; cloud computing, wireless communication, and intelligent transportation systems to manage vehicles in the complex urban network – through the use of traffic controls, route advisories, road pricing/rewards and route guidance – to jointly optimize drivers’/travelers mobility as well as achieve the sustainability goals of reducing energy usage and improving air quality. A key element of MIDAS-CPS is the real-time streaming data collection and data analysis and the subsequent traffic management through proactive traffic controls and advisories, through visualizations of predicted queues ahead, effective road prices/rewards, and route advisories. Although drivers will not be forced to use recommended routes, it is anticipated that MIDAS-CPS would lead to lesser drive stress and improved road safety, besides the designed benefits on the environment, energy consumption, congestion mitigation, and driver mobility. This talk will only focus on overall architecture of MIDAS and on the proactive traffic management component, while the on-going sponsored multidisciplinary NSF project is at the cutting edge in several areas: real-time image processing, real-time traffic prediction and supply/demand management, and data processing/management through cloud computing.

3.23 Rolling stock planning and challenges, DSB, Denmark

Morten Nyhave Nielsen (DSB – Copenhagen, DK)

The talk is divided into two parts. First, we consider the situation for DSB (Danish State Railways) in Denmark after a new contract was signed with the government in 2015, and second we look at how optimization is used in the planning proces. In the contract of 2015, the punctuality measure has changed from train punctuality to customer punctuality. Besides improving punctuality, the government also has a vision of a "one hour model" with travel times below one hour between the larger cities in Denmark. This requires huge investments in infrastructure in the years to come. Optimization software is used both for rolling stock and crew at DSB. We experience a rather large gap between developing the models/algorithms and using the theory in practice. Besides coping with all the practical details, the solutions should include features to be accepted easier by the organization and the daily planners. i.e. plan should look similar between days. Many plan starts from an existing plan, we therefore encourage the community to increase the focus on "repairing" plans instead of "generating" plans.

3.24 PANDA – A Framework for Passenger-Oriented Train Disposition

Matthias Müller-Hannemann (Martin-Luther-Universität Halle-Wittenberg, DE)

Joint work of Christoph Blendinger, Martin Lemnian, Steffen Rechner, Ralf Rückert

We introduce the decision support tool PANDA (Passenger Aware Novel Dispatching Assistance). Our web-based tool is designed to provide train dispatchers with detailed real-time information about the current passenger flow and the multi-dimensional impact of waiting decisions in case of train delays. After presenting the algorithmic background and PANDA's main features, we give a brief online demo. Besides its practical value for train dispatchers, the framework can be used to systematically study scientific questions. Exemplarily, we use our software to experimentally analyse the influence of waiting decisions on realistic passenger flow of Deutsche Bahn. In particular, we evaluate PANDA's potential benefit for passengers. Our findings indicate that a remarkable reduction in total delay might be possible.

3.25 Mathematical Modelling of Industrialized Timetables

Karl Nachtigall (TU Dresden, DE)

The computer-added generation of timetables gains noticeably importance to the strategic timetabling in railway transportation due to the application of more efficient mathematical methods and increasing computational capacities. On the one hand the computer added timetabling supports the timetabling specialist through enhancing its work efficiency. On the other hand modern timetabling methods provide the possibility to generate and evaluate several timetables. Transportation and infrastructure companies can thus analyse the available infrastructure with special respect to meaningful traffic-related measures. Therefore, the prompt, automatic and especially conflict-free generation and optimization of timetables is of special significance. The Department of Traffic Flow Science at TU Dresden is developing the programme system TAKT to automatically generate and to mathematically optimize timetables for a predetermined railway infrastructure and an associated operating program to the operator. The solution of the planning problem considers manifold diverse requirements which are partially contrary to one another. Furthermore, TAKT is able to handle large and complex real-world railway networks. This presentation gives an overview of recent research results about the mathematical modelling and solving of industrialized timetables.

3.26 O.R. for conventional rail operations in India

Narayan Rangaraj (Indian Institute of Technology – Mumbai, IN)

This talk summarizes O.R. approaches that could be fruitfully tried in the very large conventional rail system in India, especially the passenger transport segment.

In suburban services (in Mumbai, Chennai and Kolkata), there are interesting possibilities in highly resource constrained environments in timetabling and rolling stock planning. The timetables in these places are approximately periodic, but with very many special constraints including platform allocation, that make it quite challenging. Known frameworks arising from PESP may need some additional work to apply in this environment.

In long distance train services, capacity planning using a mix of simulation, scheduling theory and optimization is a potentially useful tool in many congested parts of the network. Passenger trains are handled on sections that carry significant volumes of unscheduled freight traffic (of high revenue potential) and combining goals of punctuality and throughput is quite challenging.

The rail network itself is of very large geographical spread and is very dense in parts. It is not clear what is the best way of managing such a large network in terms of decomposition of zones of control. Area control versus line or route control is one tradeoff that needs to be explored.

In the commercial domain, including in ticketing, quota allocation and revenue management, there has been significant development in the last few years, and there appears to be a lot that the O.R. and Computer Science community can contribute to.

3.27 Train routing selection for the real-time railway traffic management

Marcella Sama (University of Rome III, IT), Andrea D'Ariano, Dario Pacciarelli (University of Rome III, IT), Paola Pellegrini, and Joaquin Rodriguez

The growth of demand forces railway infrastructure managers to use the existing infrastructure at full capacity. During daily operations, disturbances may lead to conflicting requests, i.e., time-overlapping requests for the same tracks by multiple trains. The real-time railway traffic management problem (rtRTMP) aims to minimize the delay propagation using simultaneously timing, ordering and routing adjustments, decided in real-time. The problem size and the computational time required to find a good quality solution are strongly affected by the number of alternative routings available to each train. To ease the solution process, we study the train routing selection problem (TRSP). Given a railway network and n trains, the TRSP consists of selecting a subset of alternative routings for each train to be used in the rtRTMP. The TRSP is modelled using a compatibility graph G = (C, L). Each vertex in C associates a train with a feasible routing, each edge in L connects two vertices associated with different trains if the associated routings satisfy possibly existing rolling stock reutilization constraints between the two trains. The compatibility graph is thus n-partite, each component of the partition representing all the alternative routings of a given train. The cost of a vertex represents the potential delay of the associated train when using the related routing, while the cost of an edge estimates the incremental delay due to the resolution of possible conflicts arising when the two trains use the related routings. Solving the TRSP becomes thus the problem of finding m cliques having cardinality n and minimum cost. Preliminary studies of solving the TRSP, using a meta-heuristic approach, have shown very promising impact on the solution of the rtRTMP. Relevant open issues remains to be tackled, such as the definition of helpful properties for solving the TRSP, or the integration between rtRTMP and TRSP.

3.28 Approaches for integrated planning in public transportation

Anita Schöbel (Universität Göttingen, DE)

Approaches for integrated planning in public transportation

Planning of a public transportation system is so far usually done in a sequential way: After the network design, the lines and their frequencies are planned. Based on these, the timetable is set up, and later on the vehicles' schedules and the drivers' schedules. From an optimization point of view such a sequential planning procedure can be regarded as a Greedy approach: in each planning stage one aims at the best one can do. This usually leads to suboptimal solutions. On the other hand, many of these single steps are already NP hard such that solving the integrated problem to optimality seems to be out of scope.

In this talk we review line planning, timetabling and vehicle scheduling and argue that public transportation will benefit from an integrated planning. We sketch ideas and first results on exact algorithms for integrated planning (mainly suitable for special cases).

Moreover, we propose a framework, called "Eigenmodel", which can be used as basis for designing iterative approaches which re-optimize the line plan, the timetable, or the vehicle schedule while the other input is fixed (see Figure Eigenmodell). We show that such re-optimization procedures lead to new problem instances and illustrate these on re-optimizing line plan and timetable iteratively. In particular, we discuss questions about the convergence of these approaches and end with a list of challenging research questions within the Eigenmodel.

3.29 From Robustness to Resilience – How to evaluate resilience of a timetable

Norio Tomii (Chiba Institute of Technology, JP)

Recently, resilience of a timetable is attracting considerable attention. Resilience for transportation systems is defined as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events." (Transportation Research Board annual meeting 2015)

From the viewpoint of timetabling, resilience could be interpreted as a timetable which does not give much inconvenience to passengers when a rather big disruption occurs. Thus, we should assume some rescheduling is done, which is a difference from "robustness." When we assume rescheduling, we have to consider facilities such as track layouts. This means that we have to define resilience for a combination of a timetable (including crew schedules, train-set schedules), a rescheduling algorithm and track layouts. In other words, to achieve resilience of a timetable, we have to integrate a timetable, operation and facilities. There exist a huge amount of such combination and we have to develop an approach to tackle the difficulty of the combinatorial explosion.

We propose an idea to evaluate resilience assuming that a best effort rescheduling is done. We enumerate timetables and facilities and evaluate them using a best-effort rescheduling algorithm. In my presentation, I will introduce some preliminary results for simple cases.

3.30 Decision-support for railway traffic management: What can we actually conclude from previous research work and does the work meet the needs experienced by practitioners?

Johanna Törnquist Krasemann (Blekinge Institute of Technology – Karlskrona, SE)

The research efforts dedicated the last 20 years to develop different types of decision support functionalities for railway traffic management is significant. New knowledge and insight on what potential improvements that can be made and what methods there are have been transferred to practitioners. The implementation rate of developed methods is, however, still modest. Interesting questions are therefore, is the focus of the research community addressing the actual needs experienced in practice, and what is needed to bridge between research and practice?

This presentation aims to start a discussion about what we actually can conclude from previous research studies regarding 1) the requirements and needs experienced in practice and 2) the strengths, weaknesses and maturity of existing solution approaches.

3.31 The future of public transport by autonomous vehicles

Lucas Veelenturf (TU Eindhoven, NL) and Afonso Sampaio

The attention on developing autonomous cars is growing rapidly. Multiple high-tech and automotive manufacturers and universities are extensively testing these types of cars. However less attention is paid on how we are going to use this vehicles.

In this talk we assume the autonomous vehicles are available and focus on how to operationalize a public transport with autonomous vehicles. This will make it possible to shift from a supply driven to a demand driven public transport system. Several questions are raised (e.g. How many vehicles are necessary? How to route the vehicles? How to charge the vehicles? etc.)

For the routing problem, we introduced mathematical models based on existing ones in freight transportation like the Dynamic Pick-up and Delivery Problem with Transfers. Both an arc based and a path based formulation were provided of which the path based formulation seemed to be most promising. However, this path based model makes use of a time expanded graph, which can be of an enormous size. Currently we are in the phase of developing fast algorithms to solve this problem via the path based model.

3.32 Engineering Graph-Based Models for Dynamic Timetable Information Systems

Christos Zaroliagis (CTI & University of Patras, GR)

Joint work of Alessio Cionini, Gianlorenzo D'Angelo, Mattia D'Emidio, Daniele Frigioni, Kalliopi Giannakopoulou, and Andreas Paraskevopoulos

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Many efforts have been done in the last years to develop efficient algorithmic solutions for the problem of computing *best routes* in schedule-based public transportation systems. Advances in this area have been remarkable: nowadays, we have models to represent the given input timetable that allow us to answer queries for optimal journeys in few milliseconds, also at a very large scale. Such models can be broadly classified into two types: those representing the timetable as an array, and those representing it as a graph. Array-based models have been shown to be very effective in terms of query time, while graph-based ones usually answer queries by computing shortest paths, and hence they are suitable to be combined with the (very effective) speed-up techniques developed for road networks in the recent past.

In this paper, we study the behavior of graph-based models in the prominent case of dynamic scenarios, i.e., when delays might (unpredictably) occur to the original timetable. In particular, we make the following contributions. First, we consider the graph-based reduced time-expanded model and give a simplified and optimized routine for handling delays, and a re-engineered and fine-tuned query algorithm. Second, we propose a new graph-based model, namely the Dynamic Timetable Model, natively tailored to efficiently incorporate dynamic updates, along with a query algorithm and a routine for handling delays. Third, we show how to adapt the unidirectional ALT algorithm to such graph-based models. We have chosen this speed-up technique since it supports dynamic changes, and a careful implementation of it can significantly boost its performance. Finally, we provide an experimental study to assess the effectiveness of all proposed models and algorithms and to compare them with the state of the art. We evaluate both new and existing approaches by implementing and testing them on real-world timetables subject to synthetic delays.

Our experimental results show that: (i) the Dynamic Timetable Model is the best model in terms of computational time required for handling delays; (ii) graph-based models are competitive to array-based models with respect to query time; (iii) the Dynamic Timetable Model compares favorably with both the original and the reduced time-expanded model regarding space; (iv) combining the graph-based models with some speed-up techniques designed for road networks, such as ALT, is a very promising approach.

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