04261 Abstracts Collection
Algorithmic Methods for Railway Optimization
— Dagstuhl Seminar —

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Abstract. From 20.06.04 to 25.06.04, the Dagstuhl Seminar 04261 "Algorithmic Methods for Railway Optimization" was held in the International Conference and Research Center (IBFI), Schloss Dagstuhl. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

An Optimization Model for Railway Track Auctions

Ralf Borndörfer (K. Zuse Zentrum Berlin, D)

The talk discusses an auctioning approach to establish a rail track market, in which different train operating companies (TOCs) compete for tracks and timeslots on the same network.

We propose timetabled tracks (TTs), i.e., the infrastructure resources in time and space consumed by a single train, as the commodity of this market. Auctioning such TTs leads to the consideration of the Optimal Track Allocation Problem (OPTRA) to select from a set of bids for TTs a conflict free timetable of maximum value. The auction can then be organized as a sequence of OPTRAs with rising bids. The OPTRA itself can be modeled as a multicommodity flow problem, introducing a commodity for each TT, and attacked with integer programming techniques.

As the complexity of the railway system prohibits a detailed planning of TTs for relevant scenarios at this level, our implementation resorts to simplifications in network structure and train operation such as standardized dynamics and

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train types, topological simplifications, etc. such that the model can only result in a coarse plan.

In this way, scenarios covering a part of the long distance network of Deutsche Bahn form Hannover to Kassel, a time horizon of six hours, and about 1,000 bids for TTs are compuationally feasible using standard methods. First auctioning experiments indicate substantial potentials for routing additional traffic through the existing network.

Keywords: Auction, track allocation, track market, multi-commodity flow, integer programming

Joint work of: Borndörfer, Ralf; Grötschel, Martin; Lukac, Sascha

Combinatorial Structure of Periodical Timetables

Elias Dahlhaus (DB Systems GmbH - Frankfurt, D)

The talk discusses structural properties of symmetric periodical time tables.

Joint work of: Dahlhaus, Elias; Körner, H

Selfish Routing of Splittable Flow with Respect to Maximum Congestion

Rainer Feldmann (Universität Paderborn, D)

We study the problem of selfishly routing splittable traffic with respect to maximum congestion through a shared network.

Our model naturally combines features of the two best studied models in the context of selfish routing: The KP-model [Koutsoupias, Papadimitrou, 1999] and the Wardrop-model [Wardrop, 1952]. We are given a network with source nodes s_1, sink nodes t_i, $1 \leq i \leq k$, m edges, and a latency function for each edge. Traffics of rate r_i are destined from s_i to t_i. Traffics are splittable and each piece of traffic tries to route in such a way that it minimizes its private cost, where its private cost is defined as the maximum latency it experiences on an edge. The social cost of a routing is defined to be the maximum edge congestion of the network, where the congestion of an edge is defined to be the product of traffic and latency. In the absence of a central regulation, Nash Equilibria represent stable states of such a system. In a Nash Equilibrium, no piece of traffic can decrease its private cost by unilaterally changing its route. The increased social cost due to the lack of central regulation is defined in terms of the coordination ratio, i.e. the worst possible ratio of the social cost of a traffic flow at Nash Equilibrium and the social cost of a global optimal traffic flow.

In this paper, we show that in the above model pure Nash Equilibria always exist. Then, we analyze the coordination ratio of single-commodity networks

with linear latency functions. Our main result is a tight upper bound of $\frac{4}{3}m$, where m is the number of edges of the network, for the coordination ratio of single-commodity networks with linear latency functions. On our way to our main result we analyze the coordination ratio of single-hop networks and show a tight upper bound of $m+\Theta(\sqrt{m})$. A more sophisticated analysis yields an upper bound of $\frac{4}{3}m$ for the coordination ratio of multi-hop networks, which is then used to derive the main result for arbitrary single-commodity linear networks.

Keywords: Selfish routing, Nash Equilibrium, Coordination ratio

Combinatorial Benders' Cuts

Matteo Fischetti (Universitá di Padova, I)

Many railways optimization problems can be modeled as Mixed-Integer Programs (MIP's) involving logical implications modelled through big-M coefficients, which are notoriously among the hardest to solve.

In this paper we propose and analyze computationally an automatic problem reformulation of quite general applicability, aimed at removing the model dependency on the big-M coefficients. Our method is particularly suited for the MIP's whose objective function only depends on the integer variables, and the continuous variables are linked to the integer ones through linear constraints involving a single binary variable each–typically multiplied by a large coefficient. This is precisely the situation arising in many important combinatorial problems modelled by the big-M technique, where the continuous variables are only used to certify a certain property of the feasible solutions (e.g., time-windows in scheduling problems, piece non-overlapping in nesting problems, etc.). Our solution scheme defines a master Integer Linear Problem (ILP) with no continuous variables, which contains combinatorial information on the feasible integer variable combinations that can be "distilled" from the original MIP model. The master solutions are sent to a slave Linear Program (LP), which validates them and possibly returns combinatorial inequalities to be added to the current master ILP. The inequalities are associated to minimal (or irreducible) infeasible subsystems of a certain linear system, and can be separated efficiently in case the master solution is integer.

The overall solution mechanism resembles closely the Benders' one, but the cuts we produce are purely combinatorial (hence their name, Combinatorial Benders' Cuts) and do not depend on the big-M values used in the MIP formulation. This produces an LP relaxation of the master problem which can be considerably tighter than the one associated with original MIP formulation. Computational results on two specific classes of hard-to-solve MIP's indicate the new method produces a reformulation which can be solved some orders of magnitude faster than the original MIP model.

Keywords: Mixed Integer Programming, Benders' cuts, Computational Analysis

Joint work of: Fischetti, Matteo; Codato, Gianni

Capacity Assignment considering Circulations

Sven Grothklags (Universität Paderborn, D)

We present an integer programming model for the capacity assignment problem of rolling stock to trips/lines. For a fixed given schedule it has to be determined which train types should be assigned to the trips in order to maximize the profit.

The revenue, that you can achieve, depends on the seating capacity of the train you assign to a trip (or line) but is limited by a given maximal passenger demand for every trip/line. The costs consist of variable costs depending on the train type assignment to a trip and of fixed costs for the number of vehicles (train units) actually needed to cyclically operate the schedule.

The main modeling challenge comes from the fact that you must ensure that there is a legal cyclic vehicle schedule (no vehicle sources or sinks) for the computed assignment and that you are able to control and count the number of vehicles needed. Furthermore, the model must be able to deal with shunting, as trains operating a trip can consist of a number of (even different) train unit types and you have the possibility to form new train combinations at the end of a trip.

We present a model respecting the requirements from above which results in an integer multi commodity min cost flow problem that can be formulated as a MIP and solved by standard MIP solvers (CPLEX/Coin). Preliminary computational results show the suitability of this model for the long distance train network of Deutsche Bahn. The capacity allocation problem for a typical day could be solved within less than one minute on standard PC hardware using CPLEX.

Center Hub Location Problems

Horst W. Hamacher (TU Kaiserslautern, D)

Given a traffic network, the hub location problem consists of two parts: The choice of a subset of the nodes as hubs and the allocation of each of the other nodes to (one or more) of the hub nodes. Between the hub nodes, traffic is accelerated by using faster means of transportation (corresponging to the multiplication of the edge weights by a factor less than 1). Traffic between nodes is exclusively organized via hub nodes. Hub location models are used to optimize multimodal traffic systems.

In this talk some results regarding center hub location problems are presented. The objective is to minimize the maximal distance between any pair of nodes in the hub network. A new integer programming formulation is presented which leads to faster solution times compared with previous formulations, the complexity of the hub selection and the hub allocation problem is discussed, heuristics are presented and the feasibility polyhedron is investigated.

Keywords: Multimodel traffic, hub location, center obejctive, integer programming models, complexity, heuristic, polyhedral representation

Joint work of: Ernst, Andreas; Hamacher, Horst W.; Jiang, Houyuan; Krishnamoorthy, Mohan; Woeginger, Gerhard

Crew scheduling when tracks are outside service.

Dennis Huisman (NS Reizigers - Utrecht, NL)

When tracks are outside service for maintenance for a certain period, trains cannot be operated at those tracks. The rolling stock and the crew need to be rescheduled. In this presentation, we present some preliminary research on the rescheduling of crews.

Keywords: Crew scheduling, track maintenance

Train Scheduling: A Real Case

Laura Ingolotti (Univ. Politèc. de Valencia, E)

We propose to add new trains on an heterogeneous high-loaded railway network minimizing the traversal time of each new train

Keywords: Planning and Scheduling, Railway Scheduling Problem

Joint work of: Barber, Federico; Tormos, Pilar; Lova, Antonio; Ingolotti, Laura; Salido, Miguel A.; Abril, Montserrat

Delay Management

Riko Jacob (ETH Zürich, CH)

A railway operator faces at real-time the decision, whether some train should wait for a delayed connecting train, by this spreading the delay, or if the train should depart as scheduled such that the connecting passengers have to wait for the next connection.

We consider the offline setting of simplified models of this setting and show that very simple versions of the problem are already NP-hard, and complement this picture with some polynomial time solvable cases.

Joint work of: Jacob, Riko; Gatto, Michael; Peeters, Leon; Schöbel, Anita; Widmayer, Peter

A decision-support tool for strategic questions of restructuring rolling stock

Julie Jespersen (DSB S-Tog - Copenhagen, DK)

The presentation describes a decision tool for making important strategically decisions. A general model has been formulated that allows easy reformulation of the objective. The model is a linear model with a short runtime. It was initiated by various questions such as which general form of timetable to choose or whether to convert some of the new trains ordered to trains of half the length. The solutions of the model have functioned as support for such fundamental decisions.

First an introduction of the problem is given and the uncertainties are presented. Afterwards the model is presented along with its' various uses.

Railway Crew Scheduling

Niklas Kohl (Carmen Consulting, DK)

I present an overview of the work we have done on railway crew pairing and crew rostering problems at Carmen.

Keywords: Crew scheduling, crew pairing, crew rostering

Models for Rolling Stock Circulation Planning

Leo G. Kroon (Erasmus Univ. - Rotterdam, NL)

This presentation describes models for supporting the planning of the circulation of a number of train units. We will describe both a capacity allocation model for fairly allocating the train units during the rush hours, and a model for determining the details of the circulation of the train units during the day. The latter model takes into account the details of the positions of the train units in the trains, since these are important for determining the feasibility of the transition of a certain train composition to another (shunting).

Keywords: Rolling stock circulation, Capacity allocation, Branch & Cut

Periodic timetabling: a stochastic programming approach

Leo G. Kroon (Erasmus Univ. - Rotterdam, NL)

Real-time railway operations are subject to stochastic disturbances. However, railway timetables are deterministic plans.

Therefore, when a timetable is generated, the stochastic disturbances in the operations should be taken into account as well as possible. In this presentation, we describe a stochastic programming approach to handle this design problem. One of the results of this research is that, in order to minimize the average delays, the distribution of buffer times should be different from the distribution that is usually applied in practice.

Keywords: Periodic timetabling, stochastic programming

A Step Towards an Integration of Line Planning and Periodic Timetabling

Christian Liebchen (TU Berlin, D)

We propose to model relevant decisions of line planning within the Periodic Event Scheduling Problem (PESP), which is commonly used for periodic timetable optimization.

Keywords: Periodic Timetabling, Line Planning, PESP, MIP model

Joint work of: Liebchen, Christian; Möhring, Rolf H.

Finding all attractive train connections by multi-criteria Pareto search

Matthias Müller-Hannemann (TU Darmstadt, D)

We consider efficient algorithms for timetable information in public transportation systems under multiple objectives like, for example, travel time, ticket costs, and number of interchanges between different means of transport.

In this paper we focus on a fully realistic scenario in public railroad transport as it appears in practice while most previous work studied only simplified models. Algorithmically this leads to multi-criteria shortest path problems in very large graphs. With several objectives the challenge is to find all connections which are potentially attractive for customers. To meet this informal goal we introduce the notion of relaxed Pareto dominance. Another difficulty arises from the fact that due to the complicated fare regulations even the single-criteria optimization problem of finding cheapest connections is intractable. Therefore, we have to work with fare estimations during the search for good connections. In a cooperation with Deutsche Bahn Systems we realized this scenario in a prototypal implementation called PARETO based on a time-expanded graph model. Computational experiments with our PARETO server demonstrate that the current central server of Deutsche Bahn AG often fails to give optimal recommendations for different user groups. In contrast, an important feature of the PARETO server is its ability to provide many attractive alternatives.

Keywords: Timetable information system, multi-criteria shortest paths, relaxed Pareto dominance, modeling

Joint work of: Müller-Hannemann, Matthias; Schnee, Mathias

The Railway Traveling Salesman Problem

Evangelia Pyrga (CTI - Patras, GR)

We consider the Railway Traveling Salesman Problem (RTSP) problem in which a salesman using the railway network wishes to visit a certain number of cities to carry out his/her business, starting and ending at the same city, and having as goal to minimize the overall time of the journey. RTSP is an NP-hard problem that differentiates from the related Generalized Asymmetric Traveling Salesman Problem.

In this paper, we present a modelling of RTSP as an integer linear program based on the directed graph resulted from the timetable information. Since this graph can be very large, we also show how to reduce its size without sacrificing correctness.

Finally, we provide the results of some preliminary experiments with synthetic data that demonstrate the superiority of the size reduction approach.

Joint work of: Hadjicharalambous, Georgia; Pop, Petrica; Pyrga, Evangelia; Tsaggouris, George; Zaroliagis, Christos

Efficient Models for Timetable Information

Frank Schulz (Universität Karlsruhe, D)

We consider two approaches that model timetable information in public transportation systems as shortest-path problems in weighted graphs. In the time-expanded approach every event at a station, e.g., the departure of a train, is modelled as a node in the graph, while in the time-dependent approach the graph contains only one node per station.

In this talk, an experimental comparison of the two approaches is presented. Using several real-world data sets we evaluate the performance of the basic models and of several extensions towards realistic modelling. Furthermore, new insights on solving bicriteria optimization problems in both models are shown.

The time-expanded approach turns out to be more robust for modelling more complex scenarios, whereas the time-dependent approach shows a clearly better performance.

Decision-support Systems for Customer-oriented Dispatching

Leena Suhl (Univ. Paderborn, D)

We present a distributed agent-based simulation system, consisting of autonomous agents for passengers, trains, stations, dispatchers, and so on. The system can be used to test and evaluate online dispatching strategies. We present evaluation results on the complete passenger rail network of Deutsche Bahn.

Keywords: Railways, simulation, agent-based systems

Joint work of: Suhl, Leena; Biederbick, Claus

Minimum Cycle Basis of graphs and PESP

Kavitha Telikepalli (MPI für Informatik, D)

The periodic event scheduling problem can be modelled as a digraph where each vertex corresponds to a periodic event. A scheduling of the vertex set needs to be found. It is NP-hard to determine if there exists a feasible schedule. A backtracking algorithm which enumerates all functions can be sometimes sped up if a minimum cycle basis of the underlying undirected graph is used for enumeration. The main focus of this talk is on a faster algorithm for computing minimum cycle basis of undirected graphs.

Keywords: Cycle basis, periodic event scheduling

Joint work of: Mehlhorn, Kurt; Michail, Dimitrios; Paluch, Katarzyna; Telikepalli, Kavitha

Non-Additive Shortest Paths

George Tsaggouris (CTI - Patras, GR)

The non-additive shortest path (NASP) problem asks for finding an optimal path that minimizes a certain multi-attribute non-linear cost function. In this paper, we consider the case of a non-linear convex and non-decreasing function on two attributes. We present an efficient polynomial algorithm for solving a Lagrangian relaxation of NASP.

We also present an exact algorithm that is based on new heuristics we introduce here, and conduct a comparative experimental study with synthetic and real-world data that demonstrates the quality of our approach.

Keywords: Shortest paths, bicriterion optimization

Joint work of: Tsaggouris, George; Christos, Zaroliagis

Combining Speed-up Techniques for Shortest-Path Computations

Thomas Willhalm (Universität Karlsruhe, D)

Computing a shortest path from one node to another in a directed graph is a very common task in practice. This problem is classically solved by Dijkstra's algorithm. Many techniques are known to speed up this algorithm heuristically, while optimality of the solution can still be guaranteed. In most studies, such techniques are considered individually. The focus of our work is the combination of speed-up techniques for Dijkstra's algorithm. We consider all possible combinations of four known techniques, namely goal-directed search, bi-directed search, multi-level approach, and shortest-path bounding boxes, and show how these can be implemented. In an extensive experimental study we compare the performance of different combinations and analyze how the techniques harmonize when applied jointly. Several real-world graphs from road maps and public transport and two types of generated random graphs are taken into account.

Keywords: Travel planning, shortest path, Dijkstra

Joint work of: Holzer, Martin; Schulz, Frank; Willhalm, Thomas

More on optimal shunting: models and algorithms

Uwe Zimmermann (TU Braunschweig, D)

In terms of optimization, shunting can be modelled in various ways using general mixed integer programming, quadratic assignments, or graph and hypergraph colorings. Very few are efficiently solvable, most of them are NP-hard but the complexity of some is yet unknown. Tools for solving such models span the whole range from general off-the-shelf solvers like CPLEX to suitable implementations of special algorithms, including approximation algorithms and heuristical procedures.

Besides a sketch of the general landscape, we will discuss some promising models which may replace previous coloring models.