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Planning Problems in Public Transit

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Planning Problems in Public Transit*

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1 Executive Summary

Every day, millions of people are transported by buses, trains, and airplanes in Germany. *Public transit* (PT) is of major importance for the quality of life of individuals as well as the productivity of entire regions. Quality and efficiency of PT systems depend on the political *framework* (state-run, market oriented) and the suitability of the *infrastructure* (railway tracks, airport locations), the existing *level of service* (timetable, flight schedule), the use of adequate *technologies* (information, control, and booking systems), and the best possible deployment of *equipment and resources* (energy, vehicles, crews). The *decision, planning, and optimization problems* arising in this context are often gigantic and "scream" for mathematical support because of their complexity.

This article sketches the state and the relevance of *mathematics in planning and operating public transit*, describes today's challenges, and suggests a number of innovative actions.

The current contribution of mathematics to public transit is — depending on the transportation mode — of varying depth. *Air traffic* is already well supported by mathematics. *Bus traffic* made significant advances in recent years, while *rail traffic* still bears significant opportunities for improvements. In all areas of public transit, the existing *potentials* are far from being exhausted.

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For some PT problems, such as vehicle and crew scheduling in bus and air traffic, excellent mathematical tools are not only available, but used in many places. In other areas, such as rolling stock rostering in rail traffic, the performance of the existing mathematical algorithms is not yet sufficient. Some topics are essentially untouched from a mathematical point of view; e.g., there are (except for air traffic) no network design or fare planning models of practical relevance. PT infrastructure construction is essentially devoid of mathematics, even though enormous capital investments are made in this area. These problems lead to questions that can only be tackled by engineers, economists, politicians, and mathematicians in a joint effort.

Among other things, the authors propose to investigate two specific topics, which can be addressed at short notice, are of fundamental importance not only for the area of traffic planning, should lead to a significant improvement in the collaboration of all involved parties, and, if successful, will be of real value for companies and customers:

- discrete optimal control: real-time re-planning of traffic systems in case of disruptions,
- model integration: service design in bus and rail traffic.

Work on these topics in interdisciplinary research projects could be funded by the German ministry of research and education (BMBF), the German ministry of economics (BMWi), or the German science foundation (DFG).

2 Success Stories

What good is mathematics in public transit? Three examples elucidate the benefits of mathematics for the customer, the planner, and the stakeholder.

Details	Datum	Abfahrt	Ankunft	Dauer	Umst.	Verkehrsmittel
		früher				
☐	30.07.08	15:24	16:25	1:01	2	BUS U 🚶 BUS
☑	30.07.08	15:31	16:35	1:04	4	BUS BUS U S BUS
☐	30.07.08	15:44	16:45	1:01	2	BUS U 🚶 BUS

Fig. 1: Berlin's "trip info" recommends a route.

Electronic Trip Planners. Thumbing through thick timetables and railway guides in order to determine the best connection in a bus, railway, or flight network is a matter of the past. Today, bus companies, railways, and airlines offer *electronic trip planners*, which provide this information via the Internet or via mobile phones in a comfortable and fast way, always up-to-date, and at no charge. To make this service work, correct and comprehensive data is needed first and foremost. The "intelligence" to utilize this data is provided by mathematics: good methods to compute *shortest paths in networks*.[1] Appropriate algorithms for this problem are know since the nineteen-fifties. Their use in customer-friendly systems became a reality because of the rapid progress in information technology in recent years.

Examples for electronic trip planners are the "trip info" ("Fahrinfo") of Berlin's public transport company Berliner Verkehrsbetriebe (`http://www.fahrinfo-berlin.de`), see Fig. 1, the Hafas system, which is used by the German railway company Deutsche Bahn (`http://reiseauskunft.bahn.de`), and the flight search of Lufthansa (`http://www.lufthansa.de`). The basic method to compute shortest paths is *Dijkstra's algorithm*. This method has undergone many refinements and improvements over the years in order to deal with large networks and complex constraints, see [12].

Fig. 2: Flight bargains in the beginning and middle of 2008 (sources: `http://www.lufthansa.com/online/portal/lh/de/specials`, 3. 1. 2008; `http://www.airberlin.com`, 3. 6. 2008)

Revenue Management. In the middle of 2008, Lufthansa offered flights to various destinations in Europe for 99 €, see Fig. 2, Air Berlin promotes flights to Paris as cheap as 29 €, and sometimes one can find tickets for less than 10 €. How do such prices come about? They are the result of sophisticated ticket sales strategies known as *revenue* or *yield management*. The idea is as follows. Once an airline has published a flight in its schedule,

[1]Customers sometimes complain that they can find better or cheaper routes than a trip planner. This is, however, not a mathematical problem, but usually due to parameter settings such as "minimum transfer times".

it is essentially clear what the costs will be. The goal is then to maximize the revenue. There were originally two strategies to do this: the classical carriers charged high prices (and had empty airplanes on certain flights), while the low costs carriers filled their airplanes solely with cheap tickets. Today, all airlines pursue (depending on the company) different mixtures of these strategies. The clou about it is in the permanent adjustment of the booking classes and prices to the demand that has already materialized and the demand that is yet expected. Many airlines use mathematical methods of *stochastic optimization* to do these adjustments. On the basis of such forecasts, it can be reasonable to sell, at certain points in time, residual capacities at very low prices, such that at least some revenue is generated instead of flying empty seats.

The above described and at present commonly used form of revenue management was developed around 1990. In this context, the famous competition between American Airlines and the low cost carrier PeopleExpress is often mentioned, because AA finally won the fight by introducing "Super Saver" and "Ultimate Super Saver" tickets, which were sold using yield management methods. On the occasion of the bestowal of the INFORMS Edelman Award in 1991, AA provided evidence that revenue management created an additional revenue of 1.4 billion USD in the period from 1988 to 1991 [32]. After additional improvements, a benefit of even 1 billion USD per year was reported [9]. The most popular revenue management method is the *EMSR rule* (expected marginal seat revenue), which states that one should sell tickets of some booking class for a flight as long as the expected profit is positive [26]. Starting from this basic form, researchers and practitioners have developed a large variety of methods to control ticket sales, ranging from the consideration of individual flights ("leg control"), via the inclusion of simple network effects ("segment control"), to the treatment of entire itineraries ("origin destination control"), see [34] for a recent overview of the state of the art in this area of research in stochastic optimization.

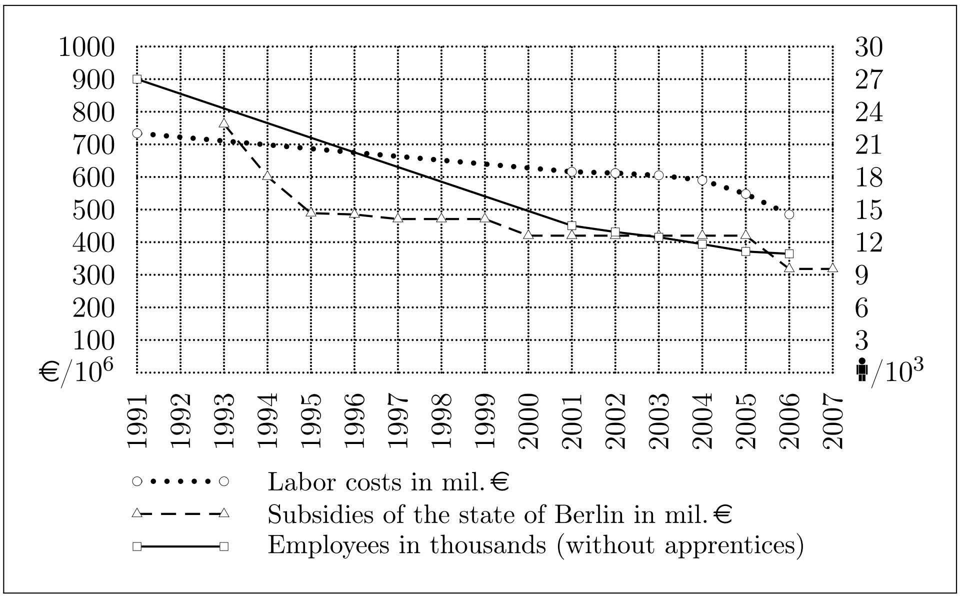

Fig. 3: Berlin's public transit company BVG in numbers (source: [33])