

Daniel Sparing: Reliable Timetable Design for Railways and Connecting Public Transport Services

Summary

This thesis focuses on railway and public transport timetable planning and optimization. The two main areas of contributions are: (1) mathematical optimization of busy railway timetables with a direct focus on timetable stability, and (2) modelling of multimodal connections between bus and railway lines. All research topics in this thesis are part of the timetabling problem of public transport, that is, choosing the arrival and departure times for train and bus services, given a certain infrastructure, available vehicles, and line structure plan, that lead to a convenient and reliable service, with extra attention to minimizing delay propagation and transfer inconvenience.

The development of a railway timetable is inherently a complex, and therefore a multi-step process, from passengers demand estimation through line planning and macroscopic timetabling to platform and track allocations and driver advisory systems. Macroscopic timetabling models in particular tend to focus either on the search for feasible timetables, or the stability analysis of existing timetable plans. These two steps result in multiple iterations of timetable generation and analysis, therefore a long planning process and possibly suboptimal timetable. A combination of these two steps into one optimization process can lead therefore for faster planning and more stable schedules. Therefore our first research objective is to develop an optimization model to maximize the stability of periodic railway network timetables.

As both railway and urban public transport networks are complex systems, most timetabling and public transport models focus on just one modality, such as railways or a metro or bus network. Furthermore, for models and journey planners that *are* multimodal, the transfer times used are often only simple norms, even in case of large and complex transfer station nodes. A large proportion of passenger journeys, however, are multimodal journeys using urban public transport as an access or egress mode for a long-distance train journey, and hence attention to intermodal transfers is crucial to improve the entire transit experience. On the other hand, in the recent years new open transit and geographical data sources became available that allow transport modelling in previously unprecedented detail. Therefore our second research objective is to model intermodal transfers in detail using open data.

The stability-optimized railway timetable

In the first part of this research we presented a formulation of the railway timetabling optimization problem that uses the minimum cycle time, a proxy for the stability of the timetable, as its objective. This is the first time that this objective was used for the optimization of a mixed-traffic railway system. This combination of the timetable planning and timetable stability evaluation problem means that as the output of the optimization

problem is a timetable optimized for network stability, the need for a large number of iterations including a timetable optimization step and a stability evaluation step is removed, improving the speed and the efficiency of the scheduling. This model is useful in practice in several steps of timetable planning process, from the actual planning of the current timetable to long term planning identifying possible line patterns and most beneficial infrastructure upgrades, to ad-hoc analysis of bottlenecks.

In order to be able to improve the stability by adjustments of train orders, running and dwell times, the mathematical optimization model uses flexible train orders, flexible running and dwell times, and flexible overtaking locations for fast and slow trains. This means that within a given line plan and stopping patterns, all these aspects of the timetable are optimized to improve timetable stability. In order to accurately model the possibility or impossibility of overtaking at certain stations or track segments, we introduced a method to expand the original set of timetable events and event pairs to allow overtaking only at the appropriate locations, without the need to explicitly model each possible consecutive train pair.

To successfully solve the optimization model for a large network in reasonable time, we used two key techniques: a set of dimension reduction techniques, and an iterative optimization method using dynamically adjusted objective bounds. We reduce the solution space by a set of techniques that take advantage of the existing symmetry of the periodic timetable to eliminate different solutions that are identical for all practical purposes. The iterative optimization is achieved by temporarily restricting the bounds of the cycle time that we are minimizing, introduce further dimension reducing constraints that take into account these temporary bounds, and after a successful or timed-out run re-adjusting the cycle time bounds accordingly until an optimal or sufficient quality timetable is reached, or the infeasibility established. With these methods we were able to define a stability-optimized timetable for the intercity network in the Netherlands, including local trains in the core, busiest area of the network, on a regular computer.

To implement this optimization model, we developed a software tool that reads common timetable formats already used by other timetable planning tools in the Netherlands, can work with a number of commercially available Mixed Integer Linear Programming solvers, and outputs the optimal timetable in the same format, as well as the related visualizations on both the planned timetable and the progress of the optimization process.

Multimodal transfer modelling

In the second part of this research, we showed how to exploit newly available open transit data to improve the modelling and therefore the timetable planning of complex transfer stations; and how to use max-plus algebra in the context of intermodal delay management. Both transit operations, and railway and transit research, often focuses at one network or one transit mode only, such as a railway network or a bus network. Passenger trips, on the other hand, are most often multimodal, combining e.g. a local

bus or tram trip with an intercity rail journey; and therefore the attractiveness or inconvenience of these multimodal transfers are key in the perceived quality of the whole public transport system. Thanks to new, open geographic databases, and publicly available transit feeds such as timetable data and Automatic Vehicle Location data, there is now data and information available at a previously unprecedented scale, that used to be hidden even from transit operators, especially concerning the network of another operator.

We focus on the detailed modelling of transfer walking times at large multimodal transfer stations, as the accurate values for transfers are essential for journey planning, timetable synchronization, and in the evaluation of the station transfer resistance. Openly available, detailed geographic data on transfer nodes can be used, with related timetable and platform allocation data connected, to build a 3-dimensional model of a transfer station including access paths, stairs, ticket gates, to improve the crude transfer time values currently used in many journey planner and timetable planning systems. These refined transfer models can in turn be used for more accurate timetable synchronization, transfer station resistance calculations, and improving dynamic, real-time passenger information, as we show in the thesis.

Finally, we use max-plus algebra to provide a formulation of the delay management problem. We combine delay propagation, the selection of important connections, and optimized holding advice in a way that is applicable even for a smaller operator, that has only influence on a smaller regional network connecting to other main networks, such as intercity train lines. The max-plus algebra-based delay propagation algorithm allows for a reduction of the solution space of the optimization problem, that is defined with arrival delays and missed connections contributing to the cost function. The output of this approach is therefore not only a holding advice for each departure at a transfer node, but also a shortlist of connections at risk, that helps dispatchers focus on the actionable transfer directions, even overriding the advice of the optimization model if they see fit.