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Robust routing and timetabling in complex railway stations

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A B S T R A C T

In nearly saturated station areas the limited capacity is one of the main reasons of delay propagation. Spreading the trains well in time and space in these areas has a big impact on the passenger robustness, i.e. the total travel time in practice of all passengers in the railway network in case of frequently occurring small delays. We focus on improving the performance in the bottleneck of the network in order to improve the performance of the whole railway network. This paper proposes a method that builds *from scratch* a routing plan and a cyclic timetable that optimizes the infrastructure occupation and the passenger robustness. An integer linear routing model assigns, without considering a timetable, every train to a route such that the maximal node usage is minimized and that the number of times that each node is used, is quadratically penalized. Thereafter, a mixed integer linear timetabling model assigns to each train the blocking times at which the nodes on its route, assigned by the routing model, are reserved and released. Different from other approaches is that we focus on the occupation of the railway infrastructure before constructing the timetable. The approach is validated on the complex railway station area of Brussels (Belgium). Our routing plan and timetable from scratch improve the passenger robustness up to 11% compared to a reference timetable and routing plan composed by the Belgian railway infrastructure manager Infrabel and by up to 2% compared to a reference timetable and routing plan from literature.

1. Introduction

Railway bottlenecks are characterized by dense train traffic and a complex infrastructure lay-out. It goes without saying that both characteristics make the planning of a bottleneck complicated, bút crucial for the performance of the whole network. Therefore it is useful to focus on the planning of a bottleneck before planning the rest of the network (Goldratt and Cox, 1986). Thereafter the planning can normally be extended and made feasible for the whole network outside this bottleneck without many changes, since typically much less constraints are present outside the bottleneck. In the first place, we want to construct *a conflict-free schedule* for the bottleneck, which means that no two trains block the same infrastructure at the same time (Caimi, 2009). Obviously, railway passengers want both short and reliable travel times. Hence, in the second place our objective is to optimize the *passenger robustness*, which means minimizing the total travel time of all passengers in practice in case of frequently occurring small delays (Dewilde et al., 2011). Unfortunately, direct implementation of this objective function is computationally highly demanding, as real travel times of all passengers and propagation of delays have to be calculated. Therefore we indirectly strive for passenger robustness by looking for an optimal spreading of the trains

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in time and space. We restrict our research to timetabling and routing, which are situated on the tactical level of railway planning. However, also line planning, on the structural level, and real-time interventions, on the operational level, have an impact on the travel times of railway passengers in practice and thus on the passenger robustness of the railway system. The timetable and routing plan construction are only designed to mitigate the effect of frequently occurring small delays on the passenger travel times. The impact of large disturbances is not considered during the construction of the timetable or routing plan. Nevertheless, we are convinced that this optimal spreading can also be useful in case of larger disturbances. To summarize, the focus of this research is on making a conflict-free and passenger robust timetable and a routing plan from scratch to transport passengers optimally in, through and out of a railway bottleneck. If a number of stations close to each other serve a high proportion of the passengers, it typically becomes a bottleneck in the railway system. We will refer to this set of stations as *a station area*. A station area can be divided in platform areas (one platform area in each station) and grid zones in between these platform areas.

The main contributions of this paper are

- A routing model and a timetabling model to construct a passenger robust and conflict-free routing plan and timetable from scratch.
- A validation of this routing model and timetabling model on a realistic, large and complex railway bottleneck, namely Brussels (Belgium).
- A routing plan and timetable which significantly improve the passenger robustness of reference routing plans and timetables from practice and from literature.
- Additive and alternative constraints to speed up routing and timetabling models and to include transfers, re-usage, splitting and coupling of trains into these models.

The proposed routing and timetabling model can be used in sequence as we illustrate in this paper. However, they can also be used independently from each other. First, in Section 2, we introduce some definitions and describe how our method is related to the state of the art in timetabling and routing for nearly saturated railway station areas. We also point out the novelties and differences of our approach. Secondly, our methodology is explained in detail. The optimization models are introduced and illustrated on a small example case study in Section 3. In Section 4, the input of the case study on the railway bottleneck in Brussels is presented together with some alternative and additional constraints to model the splitting, coupling and re-usage of trains and to speed up the models. The performance of the presented method is discussed in Section 5. The paper is concluded and ideas for future research are presented in Section 6.

2. State of the art

A railway network can be represented by a graph where switches, platforms and network border points are nodes and the tracks between these nodes are the links. From now on we will refer to switches, platforms and border nodes as nodes. *A route* in the railway network is a sequence of succeeding nodes and links. *A routing plan* is an assignment of trains to routes. It should be noted that for a station area the line planning already fixed where the trains enter and leave the area. The route planning then determines which nodes and links the trains use inside the station area. *A microscopic timetable* is an assignment of blocking times (reservation and release times) to the links and nodes on the trains' routes. For a macroscopic timetable, a routing plan is not necessarily assigned yet. *A macroscopic timetable* is an assignment, for each train, of arrival and departure times in each station on the train's line. The construction and optimization of a routing plan and a timetable are closely interwoven. The order in which both problems are solved, determines the complexity, the restrictions and the objectives of both problems. In case the timetabling problem is solved first, only a macroscopic timetable can be constructed. The routing problem, which is solved thereafter, is then constrained by the macroscopic timetable. Moreover, the routing plan fixes at the same time a microscopic timetable. Thus, in this case, the routing plan is only feasible if it incurs a conflict-free microscopic timetable. Not every macroscopic timetable, however, does assure this existence of a feasible routing plan (Sels, 2016). Thus, only after solving the routing problem, a statement can be made about the conflict-freeness of the schedule. In case the routing problem is solved first, the routing plan is not constrained by the timetable. Once the routing plan is known, not only a macroscopic timetable, but immediately a microscopic timetable can be designed. In this case the timetable is constrained by the routing plan. But also here, a conflict-free timetable does not exist for every routing plan. Only after solving the timetabling problem, a statement can be made about the conflict-freeness of the schedule. Thus, both a routing plan and a timetable are necessary to judge the conflict-freeness of the schedule.

For large networks with many stations but relatively simple infrastructure lay-out or relatively sparse traffic, it is advantageous to first construct a macroscopic timetable and only thereafter consider the routes of the trains. In a railway bottleneck, by contrast, it could be advantageous to immediately look at the microscopic infrastructure level for the construction of an optimal routing plan and timetable. This could lead to a more efficient use of the available infrastructure, as we will illustrate for our case study.

We now give a literature overview to situate our research. We divide the related approaches into three categories: approaches to construct a routing plan, approaches to construct a timetable and approaches that solve the integrated problem. For each approach we indicate which input is required, so which order of the routing and the timetabling problems this approach assumes.