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Optimization of supplements and buffer times in passenger robust timetabling

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ABSTRACT

This paper proposes an iterative approach to construct a passenger robust railway routing plan and timetable from scratch that also takes supplement and buffer time allocation into account on the signaling level. Each iteration is based on four pillars, which are subsequently executed. First a routing plan that optimizes infrastructure usage is constructed. Secondly, a timetable is constructed that optimizes buffer times between trains while taking passenger numbers into account. Thirdly, simulation is used to evaluate the passenger robustness of the routing plan and the timetable. Finally, the simulation outcome is used to make a new supplement assignment for the next iteration. The algorithm is tested on a case study for the complex station area of Brussels (Belgium). The resulting timetable and routing plan are much more passenger robust than the existing combinations of timetables and routing plans for this case, developed during research or implemented in practice.

1. Introduction

In many countries, railway passengers plan their trip based on train arrival and departure times in stations. An overview of these timings can be found in timetables published online or in the stations. In contrast to this simple overview, the operator needs a far more detailed timetable to safely and efficiently operate the railway system. Just as it is required that only one train at a time can use a platform, this also holds for other parts of the network. These parts of the network are delimited by signals and are referred to as *sections*. The signal prohibits a train driver to pass if another train is using (a part of) its next section. So the train routes have to be carefully planned from signal to signal. A timetable is *conflict-free* if no two trains are planned to use overlapping sections at the same moment. Furthermore, a lot of choices have to be considered while constructing this detailed timetable. The planning will not be efficient if train drivers are planned to stop by signals outside the platform area. Even if such an inefficient stop is not planned, it may occur in practice if trains are scheduled too tightly. There are two important factors for avoiding delay propagation: supplements and buffer times. *A supplement* is extra time that can be added in the timetable to the technical minimum running or dwell time of a train at different places on its route. *A buffer time* is extra time added to the technical minimum time that is guaranteed between two trains at a shared part of the network. Supplements are typically included such that trains can absorb their delays during operations. Buffer times can be provided such that a delayed train does not affect a next train using the same part of the network. However, the more supplements and buffer times that must be assigned, the more difficult it becomes to find a feasible conflict-free schedule. The inclusion of

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more supplements also constrains the buffer time that can be provided and the other way round. So, the inclusion of supplements and the scheduling of buffer times has to be wisely thought-out and the profit of both has to be balanced against each other to provide a good service. Even more so because supplements lengthen the travel time of the passengers, which is undesirable in case the train does not suffer from delays. Buffer times only have this disadvantage if they lengthen the transfer time between two trains.

Our objective is to construct *a passenger robust schedule*, which means that the total passenger travel time in practice in case of small daily delays is minimized (Dewilde et al., 2011; Dewilde, 2014). So travel times have to be short but also reliable in non-ideal circumstances (presence of delays).

Our methodology can be shortly summarized as follows. Starting from a given assignment of supplements, the buffer times between trains are optimized on the signaling level while constructing a feasible and conflict-free routing plan and timetable. This timetable is simulated and information on the 'causers' and the 'victims' of delay propagation are used to construct a new detailed assignment of supplements, which is the input for the next optimization round. The optimization stops when a balance between the achieved buffer times and the updated supplements is found that incurs a passenger robust timetable. The main contributions of this paper are:

- An iterative approach for computing passenger robust timetables for complex railway station areas on the signaling level.
- The heuristic improvement of both buffer times and supplements while striving for the optimal passenger travel time in practice.
- A procedure to evaluate and improve dwell and running time supplements in a timetable, based on simulation.

The focus in this paper is on the planning of complex railway station areas. The planning of such a bottleneck is at the same time complicated and crucial for the performance of the whole network (Burggraeve and Vansteenwegen, 2017). Like Burggraeve and Vansteenwegen (2017) we assume that the planning can thereafter easily be extended to the whole network. This paper proposes an approach that balances buffer times and supplements for these complex railway station areas. *A station area* consists of a number of stations close to each other, for example Brussels-South, Brussels-Central, Brussels-North and Brussels-Schaarbeek, and the grids connecting these stations with each other and with the rest of the network. We divide a station area in *platform areas*, which consist of the platforms in the stations, and *grid zones* in between these platform areas. Supplements provided in platform areas are referred to as *dwell time supplements*, while supplements provided in the grid zones between platform areas are referred to as *running time supplements*. If a train arrives with a delay on its platform, a dwell time supplement can make sure that the train leaves the station on time or with a smaller delay. In case the train is not delayed, it dwells longer, i.e. the train stands still for the minimal dwell time and the dwell time supplement. A running time supplement provides extra time for absorbing a train delay in a grid zone between two platform areas, for example when it is forced to stop at a signal because the next section is not yet free. In case the train is not delayed, it lowers its speed below its normal speed, such that it does not arrive too early on its next platform.

In Section 2, we discuss existing approaches to construct a timetable while taking buffer times and supplements into account. Then, we elaborate on our methodology in Section 3. Thereafter, a case study is described and the results for this case study are presented and discussed in Section 4 and 5 respectively. The paper is concluded in Section 6.

2. State of the art

Timetables can be constructed on the microscopic scale (signaling level) and on the macroscopic scale. Planning on the macroscopic scale only provides arrival and departure times in stations, but does not guarantee that conflict-free train routes through the network can be assigned to guide the trains to their platform at the scheduled times. Cacchiani and Toth (2012) published a literature review on macroscopic timetable models, like the Periodic Event Scheduling Problem (e.g. Serafini and Ukovich, 1989; Liebchen and Möhring, 2007; Schmidt and Schöbel, 2015; Burggraeve et al., 2017) and the Train Timetabling Problem (e.g. Caprara et al., 2002; Cacchiani et al., 2016).

Planning on the microscopic scale guarantees a conflict-free timetable on the signaling level. This implies that the timetable can be plainly implemented in practice, but it is more complex to construct a microscopic timetable since much more constraints have to be taken into account. Existing literature focuses on how to check a macroscopic timetable for feasibility on the microscopic scale and how to optimally adapt this macroscopic timetable to obtain this feasibility in case it is not microscopically conflict-free (e.g. Bešinović et al., 2017). The existing approaches differ from our approach in the fact that we purely focus on the signaling level. This is because for complex railway station areas with many switches and route options, constructing a timetable on the signaling level seems the only way to avoid many trial and error iterations and to reach an optimal infrastructure usage of these areas. Also Caimi et al. (2009) focus on the construction of a conflict-free timetable and routing plan for networks that they divide in condensation zones, where capacity is limited, e.g. dense stations, and compensation zones, where the traffic is less dense, e.g. corridors. They remove time reserves to the compensation zones, which is not recommended for large and complex railway station areas which contain multiple platform areas close to each other and a very high number of routes. This is shown in Section 5.

We now first describe the work of Sels et al. (2016) and Bešinović et al. (2016) which both developed integrated approaches for railway routing and timetabling by using an interaction between the macroscopic and the microscopic scale.

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