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Designing alternative railway timetables under infrastructure maintenance possessions

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ABSTRACT

Increasing supply in railway networks comes at the cost of an increased need for infrastructure maintenance. This also means adjusting the timetable due to long maintenance or constructions' possessions. In this article, we introduce the Train Timetable Adjustment Problem (TTAP), which for given station and open-track possessions, finds an alternative timetable that minimizes the deviation from the original timetable. We propose a mixed integer linear programming (MILP) model for solving TTAP, and apply retiming, reordering, short-turning and cancellation to generate alternative timetables. The model represents an extended periodic event scheduling problem (PESP) formulation and introduces new constraints for cancelling and retiming train lines, while short-turning is being applied in a preprocessing step. In order to solve larger and more complex instances, we use a row generation approach to add station capacity constraints. The model solves real-life instances with multiple possessions for a large area of the Dutch railway network in reasonable time, and could be up-scaled to the complete Dutch network. Additionally, it may be applicable for disruption management after some modifications. Operators and infrastructure managers could use it to automatically generate optimal alternative timetables on the macroscopic level in case of maintenance or construction works and thus, coordinate traffic for the complete network.

1. Introduction

Public transport is seen as one of the main instruments in dealing with the increasing challenges related to personal mobility such as air pollution and traffic congestion. With its high speed and capacity, railway transport is one of the main drivers and often forms the backbone of a wider public transport network. In the Netherlands, the main Dutch train operating company Netherlands Railways (NS) saw an increase in passenger numbers from 1.1 to 1.2 million per day between 2006 (Kroon et al., 2009) and 2015 (NS, 2016). One of the main reasons for this increase in demand was the higher number of trains running and the improved level of service (Kroon et al., 2009). IMPROVERAIL (2003) indicated that the increased number of train services results in a higher need for maintenance, which induces a range of planning problems on itself. Infrastructure maintenance often includes the possession of tracks, which interferes with regular traffic operations. According to RailNetEurope (2015), a possession indicates the "non-availability of part of the rail network for full use by trains during a period reserved for the carrying out of works", (e.g., the possession of two platform tracks at a station). Reducing the

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available infrastructure may make the originally planned timetable impossible to operate. Hence, an adjusted timetable has to be generated with the goal of maintaining a high level of service. This process involves a chain of decisions, which is still done manually in most countries (Lidén, 2015). Commonly, planning departments at railway companies consist of a group of people and need several weeks to generate a single feasible solution for one day of operation. Therefore, mathematical models could significantly speed up this process and design more efficient solutions that would lead to adjusted timetables of higher quality and better passenger satisfaction.

Much research has already been devoted on how to provide passengers the best supply in both regular and disturbed conditions. Models have been built to make, or at least support, decisions on the strategic, tactical and operational level, and some of them have already been implemented in practice. In addition, we distinguish macroscopic and microscopic models, based on the considered level of infrastructure details. Macroscopic models consider stations as nodes and tracks as arcs between them, with given capacities, while microscopic models incorporate details such as block sections and corresponding signalling constraints. Most of the attention in railway planning has been dedicated to macroscopic models. One of the main planning tasks on the tactical level is designing a timetable, known as the Train Timetabling Problem (TTP). A timetable consists of two building parts. First, it includes arrival, departure and through times at stations and some other important locations such as junctions and meeting points (called *event times*). Second, these event times are connected by a set of dependencies that represent train running and/or dwelling times, or infrastructure constraints. For networks with dense railway traffic, a timetable is often defined on a periodic basis, which means that train services are repeated every given cycle. Commonly, the cycle time is equal to one hour and timetables have been generated using models based on the periodic event scheduling problem (PESP). For an extensive overview of timetabling models, the reader is referred to the survey of Cacchiani and Toth (2012). Liebchen (2008) elaborated on the first real-life application of the PESP model – the Berlin subway timetable put in practice in December 2004.

In December 2006, NS introduced a new timetable which had been generated from scratch and developed by an operations research-based tool called *Designer of Network Schedules* (DONS), which is described in Kroon et al. (2009). DONS is based on PESP and finds a feasible timetable using constraint programming techniques (Schrijver and Steenbeek, 1993). Only one year after new planning tools had been implemented, passenger numbers had increased with 2.8% and annual profit with 10 million euros, while the train punctuality improved from 84.8 to 87.0% (Kroon et al., 2009).

An originally generated timetable can however become infeasible when infrastructure maintenance has to be executed. In other words, not all trains will be able to operate due to limited infrastructure availability. In the Netherlands, the infrastructure manager ProRail defined a framework for scheduling maintenance possessions (ProRail, 2014). The team at NS consists of 40 planners to develop adjusted timetables and starts designing them six months before the actual maintenance. Planners need about 14 weeks to generate a single feasible solution for one day of operation. Adjusting a timetable is done manually using a visual support system called *DONNA* and each planner focuses only on a small part of the network and uses different measures such as rerouting, cancelling or delaying trains, short-turning and changing coupling patterns, based on his or her experience (Engel, 2016).

This article presents a new model to automatically generate alternative railway timetables, taking into account possessions that span one or multiple days. Hence, it can be used by the infrastructure manager to generate the tentative alternative timetable. We define this problem as the Train Timetable Adjustment Problem (TTAP). Given an existing timetable with scheduled arrival, departure and passing times, and a list of unavailable track sections due to maintenance, the goal is to find a corresponding alternative timetable. The model considers measures such as adjusting event times, reordering, short-turning and cancelling train lines completely or partially (i.e., *short-turning*). To do so, we extend the PESP formulation by introducing new constraints for station capacity and cancelling trains. The objective is to minimize the number of cancellations and the deviation from the originally scheduled event times in the timetable. In this article, we focus on the periodic version of TTAP, but the model can be easily adjusted to solve non-periodic versions as well.

The main contributions of this article are the following:

- The first model for adjusting periodic timetables due to multiple possessions.
- A new formulation based on PESP constraints for adjusting periodic timetables that minimizes changes in the timetable, by retiming and (partially) cancelling trains.
- A preprocessing module to decide upon the short-turning of trains in case of complete possession of tracks on a corridor.
- New constraints for capacity occupation in stations.
- Applying row generation to reduce the computational times for station capacity modelling.
- Tested on real-life instances in the Netherlands.

The remainder of this article is organised as follows. Section 2 shows that the current research is still quite limited and indicates the added value of our research. Section 3 gives an introduction to the PESP model, defines the TTAP and limits the scope of this article to predetermined types of possessions and measures. We developed an exact integer programming model for solving TTAP, which is elaborated on in Section 4. Next, the proposed model is applied to a number of Dutch real life scenarios and their results are presented (Section 5). Section 6 gives an overview of the results and indicates possible directions for future research.