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Application of an iterative framework for real-time railway rescheduling ☆

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ABSTRACT

Since disruptions in railway networks are inevitable, railway operators and infrastructure managers need reliable measures and tools for disruption management. Current literature on railway disruption management focuses most of the time on rescheduling one resource (timetable, rolling stock or crew) at the time. In this research, we describe the application of an iterative framework in which all these three resources are considered. The framework applies existing models and algorithms for rescheduling the individual resources. We extensively test our framework on instances from Netherlands Railways and show that schedules which are feasible for all three resources can be obtained within short computation times. This case study shows that the framework and the existing rescheduling approaches can be of great value in practice.

1. Introduction

Railway transportation plays an important role in the lives of many people. They travel by train to their work or school, or for leisure purposes. One of the most important criteria for passenger satisfaction is the reliability of the journeys. However, disruptions like accidents, malfunctioning infrastructure or rolling stock, or crew unavailability are inevitable in a railway system. As a consequence, passengers face cancelled, delayed or overcrowded train services. It is very important for railway operators to reduce the nuisance caused by these disruptions for the passengers as much as possible.

As stated in the overview paper by Cacchiani et al. [2]: "*the development of algorithmic real-time railway rescheduling methods is currently still mainly an academic field, where the research is still far ahead of what has been implemented in practice.*" The models and algorithms from literature mainly deal with rescheduling either the timetable, or the rolling stock, or the crew. It is currently unknown whether it is possible to combine the algorithms for individual resources and come up with an overall feasible solution that is satisfactory for the passengers. A solution is overall feasible if the three resource schedules are feasible in themselves and are mutually compatible. The latter means that both rolling stock and crew are available for each trip in the timetable. This might be one of the reasons why the models from literature have not been implemented in practice yet.

In this paper, we make a first step in bridging this gap between theory and practice, by introducing an iterative framework for timetable, rolling stock, and crew rescheduling. We show that a satisfactory, overall feasible solution can usually be found in only a few iterations. This suggests that the approaches for rescheduling individual resources can be combined and applied in practice during a disruption.

In the iterative framework, we use earlier published models and algorithms on (macroscopically) adjusting the timetable, rescheduling the rolling stock, and rescheduling crew schedules. The framework first computes a new timetable. Then, it reschedules the rolling stock, covering as many trips in the timetable as possible. Trips that cannot be covered by rolling stock are then

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[1] In memoriam of Leo Kroon, who passed away on September 14, 2016.

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cancelled in the timetable. Finally, the crew duties are rescheduled. Again, the objective is to cover as many trips from the timetable as possible. If some trips cannot be covered by crew, these trips are cancelled, and another iteration of the framework is necessary. Otherwise, if all trips are covered by crew, the algorithm terminates. We emphasize that our framework is very generic: Instead of the particular models and algorithms we use, other methods can be used in the framework as well, as long as they solve a similar problem.

We demonstrate the effectiveness of the iterative approach on real-world instances from Netherlands Railways (Nederlandse Spoorwegen, or NS). We consider 976 instances in total. In half of them, one of the tracks between two stations is blocked for a certain period of time. Then, only limited train traffic is possible between these stations. In the other half, all tracks between two stations are blocked and no train traffic is possible at all. The most important objective is to minimize the total duration of the cancelled train services.

The contribution of this paper is threefold. Firstly, we introduce an iterative framework to reschedule the timetable, rolling stock, and crew. This all-in-one framework leads to an overall feasible solution for all resources. Secondly, we show that the algorithm converges to a satisfactory solution for all considered real-world instances in a few iterations. This shows that the proposed iterative approach is sufficient and suggests that an integrated approach is not required to obtain satisfactory solutions that are overall feasible. Thirdly, we show that the framework and the underlying algorithms that we use are able to solve practical problems and can be of great benefit to railway operators. In this way, we hope to reduce the earlier mentioned gap between theory and practice.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature. Section 3 contains a description of the iterative framework. This section includes a short description of the algorithms we use to reschedule the individual resources. In Section 4, we present results on 976 disruptions on the railway network in the Netherlands. Finally, we finish the paper with some concluding remarks in Section 5.

2. Literature review

A disruption usually causes the timetable, the rolling stock schedule, and the crew schedule to be infeasible. The timetable and rolling stock schedule may contain trips that make use of infrastructure that is temporarily unavailable. These trips cannot be operated, which might prevent some crew members to perform all tasks in their duties. As a result, the resource schedules need to be adjusted. In current practice, this is mostly done manually. First, often with the help of contingency plans, the timetable is rescheduled. Then, with the new timetable as input, the rolling stock and crew tasks are rescheduled manually, one by one. This is a time consuming process, so decision support tools are most welcome.

Most of the scientific literature on railway disruption management focuses on rescheduling only one of the three resources. In this section, we will briefly review the literature on rescheduling the timetable, the rolling stock, and the crew. Fore a more in depth review we refer to Cacchiani et al. [2].

The literature on timetable rescheduling can be classified in two parts: macroscopic and microscopic timetable rescheduling. Macroscopic approaches to timetabling model the infrastructure on a high level of abstraction and usually deal with larger disruptions. For example, certain tracks might be unavailable for a couple of hours. Amongst others, Louwerse and Huisman [11], and Veelenturf et al. [16] have recently developed a macroscopic model for timetable rescheduling and have performed tests on the Dutch railway network. Zhan et al. [20] developed a different macroscopic model and tested it on the Chinese railway network.

In contrast, microscopic models consider the railway infrastructure with a high level of detail. By doing so, the propagation of delays can be modelled with high accuracy. These models are usually applied to resolve smaller disturbances, e.g., few delays of up to half an hour. We refer to D'Ariano et al. [6] and Corman et al. [5] for examples of microscopic approaches to timetable rescheduling tested on the Dutch railway system and to Lamorgese and Mannino [10] for microscopic rescheduling cases tested and implemented on the Italian and Norwegian railway network, respectively.

There are multiple papers with a focus on rescheduling the rolling stock. For instance, Nielsen et al. [12] adjusted the Composition Model from Fioole et al. [7] and applied it in a disruption management setting. In this model, the rolling stock rescheduling problem is formulated as a multi-commodity flow model. Here, the nodes correspond to stations and the arcs represent the trips between stations, or waiting inside stations. Furthermore, there is also a transition graph describing the feasible transitions of compositions in the stations. In the transition graph we have nodes representing trips for which rolling stock is required and arcs representing possible changes in the rolling stock composition between these trips. Haahr et al. [8] developed a unit based model for a similar problem, where a specific path is created for each rolling stock unit separately. The model is then solved by means of column generation. The performance of these models is compared in Haahr et al. [9] on both the Dutch and the Danish railway network.

The third resource is the crew. Multiple researchers have investigated crew rescheduling. Rezanova and Ryan [14] model crew rescheduling as a Set Partitioning Problem and solve it by column generation. In a similar fashion, Potthoff et al. [13] solve a Set Covering Problem by column generation and Lagrangian relaxation. This latter approach is extended by Veelenturf et al. [17] with the possibility of retiming some of the tasks. Using a completely different method, Abbink et al. [1] solve the crew rescheduling problem by means of an agent based system. Here, agents correspond to crew members and can swap parts of their duties.

All these papers show that models and algorithms can be used as decision support tools for rescheduling one resource individually. However, it has never been tested whether these individual rescheduling algorithms can be combined and lead to a solution that is overall feasible. If, for instance, no train driver can be found for a particular trip, it means that this specific trip cannot be executed. As a result, the timetable and rolling stock schedule become infeasible, and need to be rescheduled again. In the next section we propose an iterative framework that copes with these interactions.

There are few papers that investigate the integration of all or at least two of the rescheduling steps. However, these papers focus mainly on small or less complex railway networks. Examples are Walker et al. [19], who integrate timetable and crew rescheduling, and Cadarso et al. [3,4], who integrate timetable and rolling stock rescheduling. Cadarso et al. [3] also explicitly consider the effect of the rescheduling measures on the passenger demand and on the required seat capacity.

3. Framework

In this section, the iterative framework for real-time railway rescheduling is introduced. Furthermore, we describe the interactions between the different modules in the framework and we discuss the modules individually. Note that the modules that we