Transportation Research Part B 000 (2017) 1–29

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

A real-time conflict solution algorithm for the train rescheduling problem

Andrea Bettinelli[a], Alberto Santini[b], Daniele Vigo[c,a,*]

[a] Optit s.r.l., Viale Amendola 56/D, 40026 Imola (BO), Italy
[b] Departament d'Economia i Empresa, Universitat Pompeu Fabra and Barcelona GSE, Trias-Fargas 25, 08005 Barcelona, Spain
[c] DEI, University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy

ARTICLE INFO

Article history:
Received 4 March 2016
Revised 7 October 2017
Accepted 9 October 2017
Available online xxx

Keywords:
Railway optimization
Train rescheduling
Real-time algorithm
Heuristic

ABSTRACT

We consider the real-time resolution of conflicts arising in real-world train management applications. In particular, given a nominal timetable for a set of trains and a set of modifications due to delays or other resources unavailability, we are aiming at defining a set of actions which must be implemented to grant safety, e.g., to avoid potential conflicts such as train collisions or headway violations, and restore quality by reducing the delays. To be compatible with real-time management, the required actions must be determined in a few seconds, hence specialized fast heuristics must be used.

We propose a fast and effective parallel algorithm that is based on an iterated greedy scheduling of trains on a time-space network. The algorithm uses several sortings to define the initial train dispatching rule and different shaking methods between iterations. The performance is further enhanced by using various sparsification methods for the time-space network. The best algorithm configuration is determined through extensive experiments, conducted on a set of instances derived from real-world networks and instances from the literature. The resulting heuristic proved able to consistently resolve the existing conflicts and obtaining excellent solution quality within just two seconds of computing time on a standard personal computer, for instances involving up to 151 trains and two hours of planning time horizon.

1. Introduction

Modern railways represent a major form of transport with an ever-growing user base, as trains are flexible in terms of travelling distance (they can be used for local, regional and long-distance services) and capacity (as they are modular by nature). Furthermore, train transportation is usually the greenest transportation options for both goods and people.

Despite this, railways are confronted with the increase of operational costs and a fierce competition from other modes of transport. Many users demand more reliability in train operations: a long delay, a cancelled train, a missed connection can easily decrease the perceived quality of service and turn away potential customers.

Most of the events that negatively affect train operations (broadly called *conflicts*) happen when, for some reason, there is a difference between the nominal and the actual service. The causes of such events are usually divided into *disturbances* and *disruptions* (Cacchiani et al., 2014). The former are small perturbations of the system that are handled by network operators

---

[*] Corresponding author.
E-mail addresses: andrea.bettinelli@optit.it (A. Bettinelli), alberto.santini@upf.edu (A. Santini), daniele.vigo@unibo.it (D. Vigo).

https://doi.org/10.1016/j.trb.2017.10.005

by momentarily changing the timetable. The results of disturbances are usually minor, such as one or more delayed trains, or a platform change at a station. Disruptions, on the other hand, are major incidents that not only alter the nominal timetable, but also require changes in rolling stock and crews. The outcome of a disruption could include major delays, train cancellations, and long reroutings. Disturbances clearly happen much more often than disruptions and their impact is not to be underestimated: a train that is delayed just a few minutes can make a user miss an important connection and increase their travel time by hours. In this paper we consider both disturbances and disruptions in a unified way, by defining an algorithmics approach to handle the conflicts they cause.

Increasing systemwide reliability is crucial at every phase of the planning process. It starts at the strategic and tactical levels (budget allocation for maintenance, timetable robustness, etc.), but once at the operational level, it is almost impossible to avoid that day-to-day activities be disturbed by many kinds of unforeseen events.

When such an event occurs, it is the job of the *dispatcher* to restore the system in a working state. The job of dispatchers has been traditionally done by hand, based exclusively on their experience and practice. It was not until recent years that computer algorithms were developed with the aim of aiding the dispatchers in making the best decision that resolves the critical situation and minimises deviances from the nominal timetable.

In this paper we present such an algorithm, developed to solve the Train Rescheduling Problem (TRP): given a nominal timetable which has become infeasible because of one or more *conflicts* that have arisen, we are asked to produce a new conflict-free timetable that is as close as possible to the nominal one. Or, in case it is not possible to produce a conflict-free timetable, we need to warn the dispatcher about this and provide a timetable with the least possible number of conflicts.

Conflicts are all those situations that either can't physically happen (e.g., two trains occupying the same segment of track at the same time) or that can potentially compromise the safety of operations in the network (e.g., two trains running too close to each other in the same direction).

The algorithm presented in this paper is the result of a long lasting collaboration with Alstom, initiated by the company in 2012 with the aim of redesigning the optimisation algorithms incorporated in its Train Management System ICONIS. To this end, Alstom involved three important Italian research groups in specific research projects investigating various optimisation problems arising in the real time conflict resolution. As a result of such initial wide research effort, the team formed by Optit, an accredited spinoff of the University of Bologna, and the Department of Electrical, Electronic and Information Engineering of the University of Bologna, was selected to produce an innovative real-time conflict solution algorithm capable of taking into account the characteristics and constraints of practical applications which has been developed and industrialised during 2013, and extensively tested by Alstom in real-world contexts. Recently, the new algorithm has been fully integrated in ICONIS and will be deployed at various international Alstom customers.

The paper is structured as follows. In the next section we give an overview of how a railway system works, how it can be affected by disturbances and what it means to reschedule a train. In Section 3 we review the existing literature on the TRP, based on the classification schema given by Cacchiani et al. (2014). In Section 4 we give a mathematical description of a railway network, of train timetables and of the relationship between them. We present an heuristic algorithm for the solution of the TRP in Section 5. We then describe the instances used and provide computational results in Section 6. Finally, we draw conclusions and propose further research paths in Section 7.

2. Timetables and conflicts

Nominal timetables are the crucial part of any railway systems. They describe in detail the trip of each train, from its departure to its arrival station, including all the intermediate stations where the train stops or passes by. This includes not only those parts of the trip where the train operates passenger service, but also all the movements necessary to perform service and maintenance, e.g., rolling stock relocation, cleaning, technical service.

Every arrival and departure is scheduled at specific time slots, which are calculated in advance by taking into account physical properties (e.g., track curvature and gradient, maximum allowed speed, train length) and interaction among trains. Clearly two trains can't occupy the same portion of tracks at the same time, but other constraints usually have to be respected. For example trains have to respect *headway times*, i.e., a minimum amount of time must be left as a buffer between trains travelling in the same direction. Another example are *dwell times* at platforms, which are needed to board and alight passengers.

Timetables can be *periodic* or *aperiodic*. Periodic timetables repeat themselves at certain time intervals (e.g., every second hour and every hour during peak times). Although such timetables are usually appreciated by customers, as they are easy to memorise and use, they are difficult to implement in a competitive market where many train operators are likely to request access to the same resources at the same time. For this reason, trains are often scheduled in aperiodic timetables. The name *aperiodic* is slightly misleading, since these timetables are repeated day after day so, strictly speaking, they have a period of one day.

Timetables are implemented by assigning *tasks* to *rolling stock* and *crews*. When it comes to passenger transportation, rolling stock are usually composed of one or more locomotives and many passenger cars; or, in case of multiple unit (MU) trains (MU trains are those composed by one or more similar self-propelled train cars), by one or more MUs. A crew includes a train driver and one or more train guards. Finally, a task represents a complete trip of the rolling stock and the crew from the train origin to its destination. The set of tasks carried out by rolling stock and crews in a day is called a *shift*, or duty.

Please cite this article as: A. Bettinelli et al., A real-time conflict solution algorithm for the train rescheduling problem, Transportation Research Part B (2017), https://doi.org/10.1016/j.trb.2017.10.005