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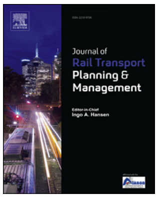

Computational decision-support for railway traffic management and associated configuration challenges: An experimental study

Johanna Törnquist Krasemann

Department of Computer Science and Engineering, Blekinge Institute of Technology, Postal Address: SE-371 79, Karlskrona, Sweden

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A B S T R A C T

This paper investigates potential configuration challenges in the development of optimization-based computational re-scheduling support for railway traffic networks. The paper presents results from an experimental study on how the characteristics of different situations influence the problem formulation and the resulting re-scheduling solutions. Two alternative objective functions are applied: Minimization of the delays at the end stations which exceed 3 min and minimization of delays larger than 3 min at intermediary commercial stops and at end stations. The study focuses on the congested, single-tracked Iron Ore line located in Northern Sweden. A combinatorial optimization model adapted to the special restrictions of this line is applied on 20 different disturbance scenarios and solved using commercial optimization software. The resulting re-scheduling solutions are analyzed numerically and visually in order to better understand the practical impact of using the suggested problem formulations in this context. The results show that the two alternative, objective functions result in structurally, quite different re-scheduling solutions. All scenarios were solved to optimality within 1 min or less, which indicates that commercial solvers can handle practical problems of a relevant size for this type of setting, but the type of scenario has also a significant impact on the computation time.

1. Introduction

A common challenge for many national railway traffic administrations is to achieve a high punctuality and ensure that the traffic system can provide reliable, attractive freight and passenger transport services. This means that the network managers need to balance the intended traffic load in the network and operator preferences with the desired network stability and timetable robustness. It also means that the occurrence of primary disturbances needs to be avoided as well as consequential knock-on delays that may occur due to congestion in the network. To what extent knock-on delays spread when a disturbance has occurred depends significantly on the ability of the timetable to absorb and recover from delays and how effectively the trains can be re-scheduled. In many railway networks, the re-scheduling is still today done manually without any computational decision-support despite that the potential benefits are evident and that the research efforts in academia as well as in industry have been intensified during the past 15 years. The challenges associated with developing, implementing and applying computational train traffic management support for different levels of decision-making are, however, extensive.

E-mail address: Johanna.tornquist@bth.se.

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The development of computational real-time railway traffic re-scheduling support is composed of three main challenges:

a) Modeling and solving the specified re-scheduling problem for various types of scenarios and contexts.
b) Requirements engineering concerning how to configure the computational support as functionalities that are perceived useful by the traffic managers and in line with the traffic management prioritization regulations.
c) Handling technical and administrative questions regarding how to incorporate the existing IT-systems and ensuring data availability.

This paper focuses on the first and second aspect and investigates potential configuration challenges in the development of a computational re-scheduling support for a larger, heterogeneous railway traffic network. More specifically, this paper presents results from an experimental study on how the characteristics of different situations and networks influence the problem formulation and the resulting re-scheduling solutions.

The study is based on the current prerequisites of the congested, single-tracked Iron Ore line located in Northern Sweden and partially Norway. A combinatorial optimization model presented in Törnquist and Persson (2007) and used earlier for a quite different context and has here been extended and adapted to the special restrictions on this line and solved using the commercial optimization software IBM ILOG CPLEX version 12.5.

The intended contributions of this paper are the proposed model extensions as well as the study of the practical implications of using the selected problem formulation for this particular context. In the study, the resulting re-scheduling solutions are analyzed both visually and numerically in detail - beyond aggregated, average numbers — in order to identify potential weaknesses and issues which cannot be identified merely by considering traditional key performance indicators related to the train delays and their recoverability.

2. Scope and related work

The research in the area of computational support for railway traffic scheduling and re-scheduling is significant. A recently published overview can be found in Cacchiani et al. (2014). Computational decision-support for re-scheduling of trains encompasses decision-making at various levels in the traffic system. It may concern the computation of the optimal train trajectory from the current train position to the next pre-determined target point in time and space for an individual train. This type of decision-support system is often referred to as Driver Advisory System (DAS), see e.g. Yang et al. (2013).

The re-scheduling may also, or instead, concern the management of the traffic system and all trains that are planned to interact within a specified time frame and part of the network. The re-scheduling decisions can be divided into re-timing, re-ordering, local re-routing and global re-routing (Hansen and Pachl, 2008). Local re-routing refers to that there are alternative paths (i.e. tracks) for the trains to use on the line between two stations or, through the stations, while global re-routing refers to that the trains can take a completely, or partly, alternative line stretch from their origin to their destination.

One sub-topic related to the re-scheduling in focus here concerns how to conceptually model and mathematically formulate the re-scheduling problem. A common way is to model the train occupation in the network in terms of train events and assign the events a set of time slots for the associated network resources. The problem of deciding i) which resource to assign to each event, ii) in what order different events should be allocated the resources and iii) during which time period, is then commonly formulated as a Mixed Integer Linear Problem (MILP) with continuous time. See e.g. one of the earlier models proposed by Carey (1994). Several extensions and other MILP formulations have later been proposed to represent more complex networks.

The re-scheduling problem is often denoted as a Job Shop Scheduling Problem with “no-wait constraints” and this has been modeled as an Alternative Graph (Mascis and Pacciarelli, 2002) and formulated as a MILP assuming that the available alternative train paths are pre-generated and that the make span is minimized (i.e. the approach minimizes the finishing time of the latest event). This approach has iteratively been extended and improved in various ways, see e.g. (D'Ariano et al., 2008), (Mannino and Mascis, 2009) and (Kecman et al., 2013). In contrast to these approaches where there is a minimization of the worse case (i.e. the maximum experienced consecutive delay) implying that the number of delays below that threshold is unregulated and not penalized, several other objectives are considered. Commonly used objectives are for example minimization of all train delays with possibilities to weight them differently and minimization of passenger delays in different ways, see e.g. (Törnquist, 2007), (Corman et al., 2012), (Sato et al., 2013) and (Dollovoet et al., 2014). There are also some recent studies investigating the application of multiple objectives and criteria, see e.g. (Samà et al., 2015).

Even though the majority of the proposed formulations use a continuous time representation, there are also several researchers who use discrete time, e.g. (Caimi et al., 2012), and (Meng and Zhou, 2014).

Many researchers use commercial solvers to solve the formulated problems. The capabilities of commercial solvers to handle these types of problems depend heavily on the problem structure, the mathematical problem formulation and the size of the problem instances. See e.g. results from comparative studies presented in Törnquist (2007) and (Harrod and Schlechte, 2013). When the commercial solvers do not provide solutions sufficiently fast, which is often the case for larger networks and time frames of 60 min or more, several researchers resort to a rolling time-horizon approach (see e.g. (Törnquist, 2007); (Meng and Zhou, 2011); (Quaglietta et al., 2013); (Pellegrini et al., 2014)), various heuristics (see e.g. (Corman et al., 2010)), parallelization approaches (see e.g. Iqbal et al. (2013)), or decomposition schemes (see e.g. (Lamorgese and Mannino, 2015)).