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Optimal train routing and scheduling for managing traffic perturbations in complex junctions

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ABSTRACT

Real-time traffic management in railway aims to minimize delays after an unexpected event perturbs the operations. It can be formalized as the real-time railway traffic management problem, which seeks for the best train routing and scheduling in case of perturbation, in a given time horizon. We propose a mixed-integer linear programming formulation for tackling this problem, representing the infrastructure with fine granularity. This is seldom done in the literature, unless stringent artificial constraints are imposed for reducing the size of the search space. In a thorough experimental analysis, we assess the impact of the granularity of the representation of the infrastructure on the optimal solution. We tackle randomly generated instances representing traffic in the control area named triangle of Gagny, and instances obtained from the real timetable of the control area including the Lille-Flandres station (both in France) and we consider multiple perturbation scenarios. In these experiments, the negative impact of a rough granularity on the delay suffered by trains is remarkable and statistically significant.

1. Introduction

Railway timetable is designed so that trains can be operated on the available infrastructure without the emergence of *conflicts*, where a conflict is represented by multiple trains concurrently claiming a portion of track. At peak hours, the capacity of the infrastructure is often fully exploited. When an unexpected event perturbs the operations, conflicts emerge and trains must be delayed for sequencing their use of the critical portions of track. This sequencing is particularly important at *junctions*, where different lines cross and share portions of track, and at stations, which are particular junctions in which trains may stop for loading and unloading purpose.

Traffic on the railway network is managed by *dispatchers*. They are in charge of smoothing operations in their *control areas*. If a control area includes a complex junction, the dispatcher task may become very challenging. At junctions, dispatchers may intervene on both train routes (*routing*) and train ordering along routes (*scheduling*) for minimizing delay propagation. In fact, for each pair of origin and destination (*o–d pair*), often multiple *routes* exist. Along these routes, trains can be stopped at selected location for scheduling purposes. Currently, few decision support tools are available for rerouting or rescheduling trains at junctions. The available tools, as for example the ARI system used in the Netherlands, may just reserve routes to trains on the basis of the timetable scheduling and on arrival time forecasts. Despite the undeniable aid of these tools, dispatchers must often take decisions autonomously (D'Ariano et al., 2008).

Several authors have proposed optimization algorithms for tackling the problem faced by dispatchers. We will refer to the formal problem tackled as the real-time railway traffic management problem (rtRTMP). In the literature, different variants of

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the rtRTMP have been tackled. These variants can be classified according to three criteria: the possibility of changing train routes, the granularity of the representation of the control area and the consideration of speed variation dynamics.

The limitation to the level of exploitation of capacity imposed by the impossibility of changing train routes is straightforward. D'Ariano et al. (2008) and Corman et al. (2010) empirically assess the large impact of this limitation, even when train routes are chosen through a heuristic.

The granularity of the representation of the control area is inversely proportional to the size of the track portions into which routes are split. As detailed in the following (Section 3), if the infrastructure is represented with fine granularity, then train routes are split into track-circuits and the route-lock sectional-release interlocking system can be modeled; if it is represented with rough granularity, then train routes are split into block sections (or even longer portions of track) and only a route-lock route-release interlocking can be modeled. Intuitively, as granularity becomes finer, the precision of the analysis, and hence the suitability of the decisions made, may increase as well. A first step in the assessment of the impact of granularity on the solution quality has been proposed by Corman et al. (2009b).

The consideration of speed variation dynamics is computationally costly and, then, hardly possible in real-time. However, the greater realism of models considering these dynamics (*variable-speed*) compared to the ones neglecting them (*fixed-speed*) is undeniable. Rodriguez (2007) reports some experimental evidence on the comparison between the solutions returned by an algorithm when considering either a variable or a fixed-speed model. The solutions of the two models are assessed in simulation. According to Rodriguez (2007), the increase of realism achieved through the variable-speed model does not pay, due to the huge additional computational effort for calculating speed variation dynamics and to the consequent limited effort available for the search space exploration. The general validity of these results has not been proven, but the number of algorithms considering fixed-speed models present in the literature, compared to the number of those considering variable-speed ones, shows that the community is quite unanimous on this validity: even if introducing a strong hypothesis, fixed-speed models are able to both capture many critical elements characterizing reality and supply solutions with a high practical relevance.

In this paper, we propose a mixed-integer linear programming (MILP) formulation for the rtRTMP. Besides considering constraints that model the relevant issues which emerge in the practice of railway traffic management, it finds the optimal solution to the rtRTMP allowing train routing along all possible routes existing in the control area. It solves instances which represent the infrastructure with fine granularity: through this formulation, we can apply either the route-lock route-release interlocking system, or the route-lock sectional-release one. Moreover, the formulation can incorporate constraints which allow its utilization in a rolling-horizon framework: we may consider time elapse in the optimization process, by solving instances representing subsequent time intervals and by considering, during each solution, the impact of the decisions previously made. In this research step, we do not consider speed variation dynamics.

We test the MILP formulation on two types of instances: random instances representing traffic in the triangle of Gagny, and perturbations of real instances representing traffic in the control area including the Lille-Flandres station, both in France. In the experimental analysis, we assess the improvement of the solution quality which we can achieve by fining the granularity of the representation of the control area, i.e., by moving from modeling a route-lock route-release interlocking system to modeling a route-lock sectional-release one. In particular, we show that granularity may have a remarkable impact on the quality of the optimal solution. We assess this impact in a thorough analysis, considering different scenarios and two objective functions measuring either total or maximum delay.

The rest of the paper is organized as follows. Section 2 reports the most relevant contributions on the solution algorithms for the rtRTMP, while Sections 3 and 4 depict the infrastructure on which this problem must be modeled and the main characteristics of the problem itself, respectively. Section 5 describes the formulation proposed in this paper. Section 6 presents the experimental setup and the instances tackled and Section 7 shows the results of the computational analysis. Section 8 reports an additional computational analysis aimed to assess the practical applicability of the formulation proposed. Finally, Section 9 concludes the paper.

2. Literature review

Several solution approaches have been proposed for tackling the rtRTMP. In this section we report the most relevant contributions, grouping them according to the granularity of the representation of the control area considered, as shortly presented in Section 1 and further detailed in Section 3.

Most of the contributions proposed in the literature represent the infrastructure with the rough granularity, i.e., splitting tracks into block sections. In some cases, the infrastructure is even represented in terms of *track segments* grouping sequences of block sections on which the train ordering cannot be changed. This is often done for modeling very large control areas. In this framework, Dessouky et al. (2006) describe a branch-and-bound algorithm for rescheduling trains using fixed routes. Törnquist and Persson (2007) propose a mixed-integer linear programming formulation allowing the change of both train scheduling and routing in a control area representing the whole South Traffic District of Sweden. However, this formulation is not strong enough for allowing the solution of the instances tackled in the paper, which include approximately 200 track segments. Hence, the authors propose strategies for reducing the feasible region of the instances and obtaining tractable sub-instances, strategies which are improved by Törnquist (2007). Törnquist Krasemann (2012) proposes a greedy heuristic for the rtRTMP, modeling track segments. All these solution approaches deal with fixed-speed models.