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A detailed analysis of the actual impact of real-time railway traffic management optimization

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ABSTRACT

Railway traffic is often perturbed by unexpected events causing delays, which may greatly propagate. Nowadays, dispatchers deal with delays trying to limit this propagation with scarce decision support tools. RECIFE-MILP is an optimization algorithm which may be used to support dispatchers' decisions. In this paper, we illustrate the analysis performed in collaboration with the French infrastructure manager (SNCF Réseau) to assess the actual impact of the application of optimization in real-time railway traffic management. We perform a twofold experimental analysis on two French complex junctions characterized by intense mixed (passenger and freight) traffic. On the one hand, we assess this impact on scenarios specifically identified as relevant by SNCF Réseau. On the other hand, we tackle actually occurred scenarios and we compare the decisions made by RECIFE-MILP with those made by the dispatchers who actually faced the perturbation. These experiments show through simulation that the optimization may remarkably improve the way traffic is managed.

1. Introduction

In railway, traffic suffers major punctuality issues that affect its competitiveness with respect to alternative modes of transport. This holds for both passenger and freight traffic. In the practice, if a train is delayed due to an unexpected event, conflicts may emerge, that is, multiple trains may claim the same track section concurrently: in this case, trains may have to stop or slow-down for ensuring safety, and delays may increase and propagate. The emergence of conflicts is particularly remarkable at junctions, that is, at locations where multiple lines cross. Here, the infrastructure capacity is often fully used, at least at peak-hours, and even slight delays may quickly propagate to several trains. Particularly, this propagation strongly affects freight trains, which are often delayed to preserve passenger trains punctuality.

Nowadays, conflicts are manually solved by railway dispatchers who may decide to reschedule trains to minimize delay propagation, that is, to change the originally planned train order at critical locations. At junctions, where several routes are available for connecting origin-destination pairs, also train routes may be changed with respect to the originally planned ones (rerouting). The scarcity of decision support tools and the limited capabilities of the existing ones complicate the task of dispatchers. In fact, dispatchers must make decisions on how to reschedule and reroute trains by comparing different options in terms of the impact of these options on the system. However, today, no tool allows dispatchers to assess this impact and

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hence to make a thorough comparison: their experience and the existing priority rules are often the only means to do so, maybe supported by graphic tools.

Several optimization algorithms have been proposed in the literature to act as a decision support tool for dispatchers. In particular, they solve different variants of the real-time railway traffic management problem (rtRTMP) (Pellegrini et al., 2014). Among these optimization algorithms, RECIFE-MILP (Pellegrini et al., 2015) makes simultaneously rescheduling and rerouting decisions and often proves the optimality of these choices. Due to the short computational time imposed by the real-time nature of the problem, in some cases the optimality of the solution cannot be proved and the best solution found at the end of the available time is returned, together with the optimality gap.

In collaboration with SNCF Réseau, the French rail infrastructure management, we performed an empirical analysis to assess the actual impact that an optimization-based decision support tool may have on traffic management. We performed this analysis in the context of the research project SIGIFret (Simulation d'une gestion innovante des circulations fret) within the French PREDIT program (Programme de Recherche Et D'Innovation dans les Transports terrestres). In the SIGIFret project, the line Paris-Le Havre was chosen as case-study due to the presence of mixed traffic and its regulation issues in two critical control areas: the stations of Mantes-La-Jolie and Rouen-Rive-Droite. In this framework, we modeled 7 km of track around the station of Mantes-la-Jolie and 27 km around the station of Rouen-Rive-Droite in the OpenTrack simulator (Nash and Huerlimann, 2004). It is a microscopic railway simulation tool, able to compute the traffic behavior according to the track topology, the signalling system and the train dynamics. This tool therefore allows the fine evaluation of the impact of different dispatching choices. We tackled several scenarios representing realistic disturbances: train entrance delays in the control area, prolonged stops at stations, impracticability of track sections, temporary speed limitation. In particular, these scenarios were chosen by SNCF Réseau as representative of the typical situations which occur on this line.

To assess the impact of the optimization, we compare the train delays after the simulation of the traffic management decisions made according to different strategies. First of all, we consider RECIFE-MILP when rerouting is either forbidden or allowed. Then, we simulate the first-come-first-served (FCFS) strategy, in which the first train claiming a track section is the first one which is allowed to go through it. Furthermore, we take into account the traffic management strategy currently preconized in France and in many European countries (RNE, 2015): between two trains claiming a track section, the most punctual train is favored and the already delayed one is stopped or slowed down. Finally, for three perturbation scenarios in the Rouen-Rive-Droite control area, we also deal with the decisions which were actually made by the dispatcher. In the following, we describe in detail each of the scenarios which occurred in reality. This allows the reader to asses their difficulty and to really understand the practical characteristics of the instances that need to be tackled in reality. For each of them, we propose the detailed comparison between the decisions of an optimization algorithm and those actually made by the dispatcher. To the best of our knowledge, in the literature, in the few papers in which actually occurred scenarios are tackled, only aggregated results are described, with no focus on the specific decisions. In our eyes, analyses as the one proposed in this paper are the best way for supporting the claim that optimization should be used in the traffic management practice.

The rest of the paper is organized as follows. Section 2 reports a brief literature review on the optimization algorithms which have been proposed for tackling the rtRTMP. Section 3 describes the RECIFE-MILP algorithm. Section 4 and Section 5 present the experimental setup and the obtained results, respectively. Finally, Section 6 reports the conclusions that can be drawn on account of these results.

2. Literature review

A noticeable number of academic studies have been devoted to finding effective algorithms for the rtRTMP. Cacchiani et al. (2014), Corman and Meng (2015) and Fang et al. (2015) propose recent reviews of these studies. We refer the interested reader to these references for a detailed analysis of the literature, and we focus here only on the most recent proposals.

Probably the most flourishing stream of research considers the formulation of the rtRTMP through alternative graphs, in the form of the algorithms ROMA (Corman and Quaglietta, 2015) and AGLIBRARY (D'Ariano et al., 2014). The infrastructure is modeled at the microscopic level and the route-lock route-release interlocking system (Theeg et al., 2009) is implemented. In this stream, D'Ariano et al. (2014) asses the performance of the alternative graph formulation solved with the CPLEX commercial solver and with the specifically designed algorithm. The instances tackled represent traffic in a portion of the English network and no specific details are given on the timetable used. Corman et al. (2012b, 2014) describe an approach to solve the problem of coordinating multiple solutions of the rtRTMP, each corresponding to a portion of a network. In the two studies, the authors validate their approach by testing it on randomly perturbed instances representing traffic in a railway network that spans over multiple dispatching areas of the Dutch railway network. The random perturbations are obtained by starting from a real timetable and by modifying the trains' entrance time in the network according to a Weibull distribution. This distribution had been previously identified as the best to describe the actually observed delays in the Netherlands. The same type of instances are used by Samà et al. (2015). In the paper, the authors propose a Data Envelopment Analysis (DEA) framework for assessing a multi-objective version of the rtRTMP. In the experimental analysis, no rerouting is allowed, which in principle speeds up the solution of the traffic management problem. However, the framework proposed does not impose any constraint in this sense, and in principle it may be used also when alternative routes are considered. Corman et al. (2012a) tackle a bi-objective version of the rtRTMP, where the minimization concerns both the maximum train delays and a measure of the missed connections. The proposed algorithm provides a set of feasible non-dominated schedules to support the dispatcher decision process. The instances tackled are obtained in the same way as in the other mentioned papers, even if a