Robustness analysis of railway rerouting and rescheduling to driving behaviour noise

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Mots-clés : *Real-time Railway Traffic Management, Scheduling and Routing, Robustness.*

1 Introduction

The real-time Railway Traffic Management Problem (rtRTMP) is a classical problem in the field of railway operations research. It consists in defining the passing orders and the arrival and departure times of trains in stations and selecting their route across the network. The aim is to minimize delay propagation, given a perturbed timetable.

Several models and algorithms have been developed to solve this problem and provide optimized decision support systems. However, besides the theoretical developments, few studies have been devoted to bringing the advanced rtRTMP solution methods closer to their practical deployment. In a laboratory environment, the precision of traffic state prediction in rtRTMP solutions can be guaranteed. However, this is hardly the case in reality: some noise will necessarily make even the best prediction module imprecise. To the best of our knowledge, this aspect has so far been neglected in the literature on rtRTMP algorithm deployment. Nonetheless, we consider it necessary to evaluate the robustness of real-time rail traffic management algorithms to cope with imperfect traffic data.

In this work, we study the robustness of the rtRTMP solution in terms of its ability to cope with train movement noise in practical deployment. We propose a closed-loop framework which integrates OpenTrack [1], a commercial railway traffic simulator, with RECIFE-MILP [2], an rtRTMP solver able to manage complex rail scheduling and routing problems.

2 Methodology

To evaluate the effect of noise on the performance of RECIFE-MILP, we use a closed-loop framework which integrates the rtRTMP solver with the OpenTrack commercial railway traffic simulator. For the whole *simulation interval*, RECIFE-MILP periodically communicates with the simulator via an Application Programming Interface (API). It receives information on the traffic state and provides routing and scheduling solutions for managing traffic in the *optimization horizon*. At each call of the rtRTMP solver, a short-term traffic state prediction is computed for all the trains expected to be operated in the control area within the optimization horizon.

Once computed, the rtRTMP solution is passed to the simulator which implements it. As time information are approximately computed in RECIFE-MILP, as in virtually all existing optimization algorithms, the API first translates this solution into the corresponding train passing sequence on each track section. Then the automatic route setting is executed in OpenTrack to implement this sequence.

In the literature, the typically considered alternative of the closed-loop framework is named open-loop. Here, the optimizer is called just once at the beginning of the simulation, and the routing and scheduling decisions it makes are then implemented without periodic re-assessment. In the following, we refer to closed-loop and open-loop frameworks as RECIFE CL and RECIFE OL, respectively.

3 Computational analysis

This section presents the computational results regarding the potential of RECIFE CL in presence of noise compared with the application of the simple First Come First Serve (FCFS) strategy, on the one hand. The FCFS can be directly implemented by OpenTrack using the timetable route for each train. On the other hand, it is compared with the one obtained using RECIFE OL. For this comparison, we use 100 instances generated from a real week-day timetable with initial perturbations on a portion of a line of the French railway network, between Paris and Le Havre. For each instance the simulation starts at 7:30 and finishes at 10:00. We then set an optimization horizon of 45 minutes for RECIFE CL, as 89% of the trains have a shorter journey time on this line. In this analysis, we consider train movement noise related to driving behavior. Specifically, we reduce the maximum speed that a train can reach on each track section by a factor randomly chosen in the range between 1 and 0.97 [3].

We perform the Wilcoxon signed rank test to analyze if the difference of total delay between traffic management approaches is statistically significant or not, in presence of noise. We consider a confidence level of 0.95. Positive values of the pseudo-median μ and of the lower and upper bounds of the confidence interval (CI) mean that the difference is significant and RECIFE CL performs significantly better than its competitor. The results in Table 1 show that RECIFE CL is significantly better than both FCFS and RECIFE OL. Therefore, the use of RECIFE CL is recommended when solving the rtRTMP: data imprecision due to noise does not make its decisions inappropriate, and the periodic update of traffic information allows RECIFE CL to adapt the solution process and make better decisions.

TAB. 1: Statistical significance at 0.95 confidence level of the performance difference in case of noise on train driving behavior.

Approach	p-value	μ	LCI	UCI
FCFS - RECIFE CL	120.2 E-18	1210	1042	1403
RECIFE OL - RECIFE CL	1.4 E-3	27	8	52

Future research will extend the robustness assessment by considering other sources of noise, and other rail infrastructures, with different characteristics from those presented here. Furthermore, different configurations for the RECIFE-MILP closed-loop framework may be studied, to identify the best values for the parameters involved in the process, such as the length of the optimization horizon and the re-optimization periodicity.

References

[1] OpenTrack Railway Technology Ltd. OpenTrack - Simulation of Railway Networks. http://www.opentrack.ch. Accessed November 14th, 2022.

[2] Pellegrini, P., Marlière, G., and Rodriguez, J., 2014. Optimal Train Routing and Scheduling for Managing Traffic Perturbations in Complex Junctions. *Transportation Research Part B*, 59, pp.58–80.

[3] SNCF Réseaux, Document de référence du réseau horaire de service 2019 annexe 4.1 : référentiel technique de tracé des sillons. Horaire de service 2020, 2018.