Self-organization for train re-scheduling and re-routing : a proof of concept

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1 Introduction

During operations, railway systems tend to suffer from performance drops linked to unexpected events. These events often generate conflicts. Specifically, a conflict occurs when two or more trains would claim a track section concurrently if they ran at the planned speed. In case of conflict, trains need to slow down or stop to maintain a safe train separation, and this leads to delay propagation. Dispatchers are in charge of traffic management. Their objective is to prevent delay propagation by making sensible re-routing and re-scheduling decisions as traffic evolves. This is formalized in the operations research literature as the real-time Railway Traffic Management Problem (rtRTMP) [2]. In practice, dispatchers tackle real-time traffic management in a centralized fashion, mostly relying on their experience alone. Also most literature addresses the problem in a centralized manner, proposing different optimization models and algorithms. Conversely, the European project SORTEDMOBILITY [3] proposes a paradigm shift : the traditional centralized envisioning of real-time railway traffic management is replaced by multiple agents (the trains) self-organising and partaking in decision making. This will bring increased flexibility and responsiveness to the decision-making process in perturbed traffic scenarios.

In this work, we showcase the original design for the self-organization process proposed in SORTEDMOBILITY. Furthermore, we provide a proof of concept on the proposed method's applicability by considering a realistic case study, based on a French railway control area.

2 Self-organized decision making

In SORTEDMOBILITY, we propose a real-time rail traffic management process based on self-organization. Multiple agents, i.e., the trains themselves, are given decision-making capabilities. Considering the current traffic and passenger demand state, such agents will generate their own proposals of re-routing and re-scheduling decisions to be implemented to minimize delay. They will participate in a consensus process to produce a Real-Time Traffic Plan (RTTP). An RTTP collects re-routing and re-scheduling decisions, and expresses how traffic shall evolve.

The SORTEDMOBILITY self-organized decision making process consists in the sequential execution of the following four modules : I) *Neighborhood selection* : each train identifies a subset of neighbouring trains that need to be taken into account, as they might be involved in a conflict in the near future. Remark that neighborhoods from different train may not be identical, and can be partially overlapping : a train can belong to various neighborhoods simultaneously. II) *Hypothesis generation* : each train generates re-routing and re-scheduling decision hypotheses in the form of multiple RTTPs, that include all trains in its neighborhood. This module is based on RECIFE-MILP [2], a state-of-the-art rtRTMP solver. In particular, for each train, the best re-routing and re-scheduling options are generated and associated with a cost proportional to the delays resulting from the specific traffic management decisions considered. Each train selfishly evaluates its own delay more important than other trains' one. III) *Consensus* : each train negotiates with its neighbors and eventually agree upon a set of compatible hypotheses, i.e., they reach consensus on a suitable set of RTTPs. Each train aims at minimizing its own cost and reach consensus. When consensus is reached, an RTTP for each train is selected. The consensus approach we implement is stochastic, and is inspired by a simple voter-model [1]. IV) *Merge* : after the consensus process, all the RTTPs selected by the trains are centrally merged into a final RTTP that is then fed to traffic control for deployment.

3 Proof of Concept

As a proof of concept, we test the process described in Section 2 on a case study representing traffic in a portion of the Paris – Le Havre line, in France. It is a 80-km mixed-traffic line including 10 stations, some of which with multiple platforms. At peak time, 15 trains traverse the control area in an hour, on average. We generate one perturbed traffic scenario by random sampling 20% of trains in the entire-day nominal timetable. Then, we apply to the sampled trains a random entrance time perturbation between five and 15 minutes. The self-organization process is run taking as input the traffic state observed every 30 minutes between 6:00AM and 12:00PM. We obtain this traffic state through the *OpenTrack* microscopic railway simulator. For each traffic state, we compare the sum of the costs that each train associates to the hypotheses chosen in the consensus process with two benchmarks. On the one hand, we compute the optimal hypothesis selection to minimize the total cost. On the other hand, we compare the total delay resulting from the consensus process with the one achievable by regulating traffic with a centralized algorithm. In particular, we use RECIFE-MILP for this comparison. Preliminary results on this scenario suggest that the consensus solutions well approximate the global optimum.

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Références

[1] Richard A Holley and Thomas M Liggett. Ergodic theorems for weakly interacting infinite systems and the voter model. *The annals of probability*, pages 643–663, 1975.

[2] Paola Pellegrini, Grégory Marlière, and Joaquin Rodriguez. Optimal train routing and scheduling for managing traffic perturbations in complex junctions. *Transportation Research Part B : Methodological*, 59 :58 – 80, 2014.

[3] SORTEDMOBILITY. Self-organized rail traffic for the evolution of decentralized mobility, 2021. Accessed October 20th, 2022.