Generalization of the train routing selection problem for real-time traffic management

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1 INTRODUCTION

In recent years, European and international transport policies have strongly promoted the shift to railway transport system, due to sustainable, environmental and energy issues. The resulting increase in railway market share is accompanied by a significant challenge: the need to guarantee an adequate level of service in terms of train punctuality.

Typically, rail operations are regulated by a fixed timetable, which defines the train passing orders, the arrival and departure times of trains in stations and their route across the network. During real-time operations, unpredictable events may cause timetable perturbations, which can lead to train conflicts, i.e., the simultaneous utilization of the same infrastructure section(s). Dispatchers are required to quickly detect new conflicts arising during operations and take actions to recover them by retiming, reordering and rerouting trains in such a way that the timetable perturbation is minimized. This problem is known in literature as the real-time Railway Traffic Management Problem (rtRTMP). Several models and algorithms have been developed to solve the problem to provide Decision Support Systems to help dispatchers take more informed decisions (Borndörfer et al., 2017). Still, the rtRTMP is NP-hard (Mascis & Pacciarelli, 2002): solving the entire problem involves a high computational effort in large instances. However, the real-time nature of the problem requires very short computational times. Simplifying the rtRTMP is thus a key aspect to achieve high quality solutions in the available computation times.

Some approaches limit the size of the problem by intervening on the granularity used to model the infrastructures and the traffic flows (Lamorgese & Mannino, 2015), or focus on the resolution process to properly drive the search of good solutions (Pellegrini et al., 2015, Samà et al., 2017). Others limit the number of variables by considering only what they perceive to be the most significant ones (Van Thielen et al., 2018). Often, rerouting variables are the ones most affecting the size of the rtRTMP search space, thus some works fix the routes in the timetable as the only option, concentrating on the pure scheduling problem, while others use subsets of all the possible alternatives available, which are either based on guidelines set by infrastructure managers, or chosen because considered the ones that will probably lead to the best quality solutions.

The need for a systematic study on the routing selection has lead to the definition by Samà et al. (2016) of the Train Routing Selection Problem (TRSP). The TRSP consists in identify promising alternative routes for each train in advance, which are then used in the rtRTMP as the set of the only possible alternative routes. In the TRSP, the benefit of using specific subsets of routes in the rtRTMP is approximated. This is assessed by considering estimations of costs due to conflict occurrence and scheduling decisions. The validity of the TRSP and the impact of its solution on the rtRTMP have been analyzed in the literature. The analysis has been performed by using a specific mixed-integer linear programming (MILP) formulation (Pellegrini et al., 2014) and the RECIFE-MILP solution approach for the rtRTMP (Pellegrini et al., 2015). RECIFE-MILP is a decision support tool developed at IFSTTAR, considering as objective function the minimization of the total train delay.

This paper proposes the generalisation of the TRSP for a different rtRTMP approach which has a different model, objective function and solution approach than RECIFE-MILP. The aim is to extend the validity of the TRSP and assess its general effectiveness for the rtRTMP. We consider for the rtRTMP the decision support system AGLibrary (Samà et al., 2017), developed at Roma Tre University, which solves an alternative graph model (Mascis & Pacciarelli, 2002) of the problem to minimize the maximum train delay. We analyze how changes in the rtRTMP model and objective function have to be reflected on the TRSP one and/or on the estimation of costs, and how this may be achieved. The computational analysis is performed on a French infrastructure: the line around the city of Rouen.

2 METHODOLOGY

We consider the rtRTMP microscopically modelled using the alternative graph formulation (Mascis & Pacciarelli, 2002): the rtRTMP is considered as a job shop scheduling problem with flexible routes and additional practical constraints. The rtRTMP is solved via AGLibrary (Samà et al., 2017), a decision support tool developed at Roma Tre University, which minimizes the maximum train delay. AGLibrary uses an iterative meta-heuristic approach for the rtRTMP. At each iteration a scheduling solution is computed for the rtRTMP and then analyzed to evaluate which rerouting action may transfer train on less congested routes, thus leading to better quality solutions, until a maximum computation time is reached or a solution with no delay is found.

In our approach, an optimized pre-processing phase is used to limit the number of routing variables in the rtRTMP. This pre-process requires solving the TRSP, and consists in selecting a feasible and optimized subset of alternative routes for each train. The route selection is based on costs associated to scheduling decision impact, in terms of train conflicts. The TRSP solution is given as input to the rtRTMP to reduce its search space and to provide better solutions.

The TRSP is modelled on a construction graph $G = (V, E)$, for which an example is given in Figure 1. Each vertex $v_i \in V$ represents an available train routing for a train. Each edge $e_{ij} \in E$ connects two vertices belonging to different trains if the associated routings satisfy possibly existing rolling stock reutilization constraints between the two trains. Such graph is k-partite and each partition $V_t \subset V$ represents all the available alternative routings for a given train $t = 1...k$. Costs are associated to vertices and edges as an estimation of the influence of choosing a particular routing on its own or in combination with another one on the final quality of the rtRTMP solution. Solving the TRSP translates into finding a certain number of minimum cost k-vertex cliques, where k indicates the number of total trains considered. A clique is a classical concept in graph theory defined as a subset of adjacent vertices. We propose alternative ways of computing the cost of a clique, in order to evaluate how changes in the rtRTMP objective function should be reflected on the TRSP.

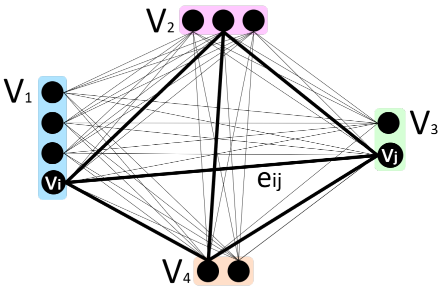

Figure 1 – *Example of a construction graph* $G = (V, E)$

We solve the TRSP using an evolution of the algorithm in Samà et al. (2016), based on Ant Colony Optimization (ACO) (Dorigo et al., 1996), a meta-heuristic inspired by the foraging behaviour of ant colonies. For the TRSP, at each iteration the ants of the colony incrementally build cliques on the construction graph. The probability of selecting a vertex is computed via the random proportional rule, using pheromone trails and heuristic information. The pheromone trails represent historical information on the quality of the already visited solutions including the vertex in exam. The heuristic information is a greedy measure of the achievable quality of the solution when such vertex is added.

3 RESULTS

The proposed TRSP-rtRTMP approach is tested on a French case study based on real-world data. It is the 27-km-long railway line around the city of Rouen, shown in Figure 2. The line is mainly on double-track with several intermediate stations, each with up to six platforms. The infrastructure is composed of 190 track-circuits, 189 block sections, and 11347 routes. On average, there are 13 trains per hour, and 62 routing alternatives per train. A train can have a maximum of 192 routing alternatives. We generated 100 instances of 60-minute time window randomly taken during the traffic peak-hours, considering multiple perturbed timetables. Timetable perturbations represent train entrance delays in the infrastructure. We perform the experiments on an Intel Xeon 22 core 2.2 GHz processor with 1.5 TB RAM, under Windows distribution.

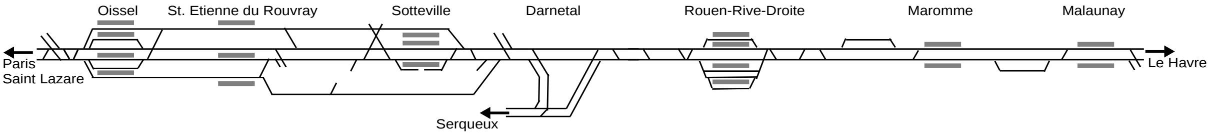

Figure 2 – *Rouen network*

We summarize the benefit of solving the rtTRSP in terms of the performance obtained for the rtRTMP in Table 1. Specifically, we report the average objective value obtained by using AGLibrary when minimizing the maximum train delay for the rtRTMP and the average computation time at which the best solution is found. We compare two different approaches used to solve the TRSP in order to generate the input for the solution of the rtRTMP:

- ACO-TRSP: A TRSP solution with p routing alternatives for each train is computed by the ACO-TRSP algorithm with a time limit of 30 seconds. This TRSP solution is given as an input for the solution of the rtRTMP by AGLibrary. A computation time limit of 150 seconds is set for the rtRTMP. The best ACO-TRSP routing for each train is set as its default routing alternative;

- ALL ROUTINGS: All routing alternatives are given as input to AGLibrary. A computation time limit of 180 seconds is set. The timetable routing is set as the default routing alternative for each train.

The numerical results shows that ACO-TRSP is able to select high quality train route combinations which enforce the objective function of the AGLibrary solver: the rtRTMP objective values improve by 25%. Furthermore, ACO-TRSP allows the computation of the best quality solution in a much shorter computation time compared to AGLibrary with all routings.

Table 1 – *Average AGLibrary-rtRTMP objective value*

Approach	p	Obj. value (s)	Time best (s)
ACO-TRSP	10	82.9	1.3
	20	81.5	4.8
	30	80.6	6.3
	50	80.8	6.0
	70	81.0	3.7
ALL ROUTINGS	192	106.5	90.0

Future research will be dedicated to apply our methodology to other rail infrastructures, with different characteristics from those presented here. Furthermore, other exact or meta-heuristic methods for the TRSP could be designed and compared.

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