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On the tactical and operational train routing selection problem ☆

Marcella Samà [a,]*, Paola Pellegrini [b], Andrea D'Ariano [a], Joaquin Rodriguez [c], Dario Pacciarelli [a]

[a] Roma Tre University, Department of Engineering, via della Vasca Navale, 79, 00146 Rome, Italy
[b] Univ. Lille Nord de France, Ifsttar, COSYS, LEOST, rue Élisée Reclus 20, 59666 Villeneuve d'Ascq, Lille, France
[c] Univ. Lille Nord de France, Ifsttar, COSYS, ESTAS, rue Élisée Reclus 20, 59666 Villeneuve d'Ascq, Lille, France

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ABSTRACT

In the real-time railway traffic management problem, the number of alternative routings available to each train strongly affects the size of the problem and the time required to optimally solve it. The train routing selection problem identifies a suitable subset of alternative routings to be used for each train in the real-time railway traffic management. This paper analyzes the impact of solving the train routing selection problem at different levels. The problem can be solved at tactical level right after the timetabling process, using historical traffic data and with abundant computation time. In this case the problem constitutes an integration step between the timetabling and the real-time traffic management. Alternatively, the problem can be solved at operational level right before the real-time railway traffic management problem solution, using up to date traffic perturbation and a real-time time limit of computation. Experiments are performed on two French test cases, the line around Rouen and the Lille station area, for several disturbed and disrupted scenarios. The results show that the best approach depends on the type of traffic disturbance tackled.

1. Introduction

Infrastructure managers experience difficulties in ensuring a good quality of service while facing the ever increasing rail transport demand. This, added to the limited space and funds available to build new infrastructure in bottleneck areas, stimulates the interest for new effective operations research solution methods. Railway problems can be grouped in three levels: strategic, tactical and operational (Lusby et al., 2011).

The problems dealing with network and line planning belong to the strategic level. These problems involve the construction of infrastructures and/or the upgrade and modification of already existing ones, assessing in particular the impact on the capacity of the overall system (Bussieck, 1998; Goossens et al., 2005; Goverde et al., 2013; Scholl, 2005).

The problems dealing with the creation of plans for the infrastructure utilization belong to the tactical level. Railway operations usually follow a timetable, carefully designed in advance in terms of routing assigned to each train, orders between trains on common tracks and timings on the resources (Cacchiani and Toth, 2012; Carey and Carville, 2003; Carey and Crawford, 2007; Sels et al., 2014; Serafini and Ukovich, 1989; Zwaneveld et al., 2001). Robustness considerations are often introduced in the timetables to prevent that strong traffic disturbances make these plans not implementable

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* Corresponding author.
E-mail address: sama@ing.uniroma3.it (M. Samà).

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(Cicerone et al., 2008; Liebchen et al., 2009; Schöbel and Kratz, 2009). However, even a robust timetable may not be able to cope with severe real-time disturbances (Corman et al., 2014; Larsen et al., 2014; Zhan et al., 2015; Zhan et al., 2016).

The problems dealing with the creation of working timetables in real-time belong to the operational level. These working timetables are required when disturbances arise and the tactical timetable becomes infeasible (Cacchiani et al., 2014; Corman and Meng, 2015; Fang et al., 2015). A main problem tackled at this level is the real-time Railway Traffic Management Problem (rtRTMP) (Pellegrini et al., 2014). The rtRTMP consists in detecting conflicting track requests by several trains during disturbed operations and solving them through routing, ordering and timing decisions in order to obtain a new efficient feasible plan of operations where no deadlock exists.

The minimization of the propagation of delays is probably the most widely used objective function at operational level, which takes different forms in the literature (Samà et al., 2015, 2017). Some works minimize the maximum (D'Ariano et al., 2007; Mazzarello and Ottaviani, 2007; Samà et al., 2017) or total (Meng and Zhou, 2011; Pellegrini et al., 2014; Rodriguez, 2007) delay introduced in the system by train dispatching decisions. Others focus on the minimization of the deviation of the working timetable from the tactical one (Caimi et al., 2012) or address the trains arrival time at destination (Dessouky et al., 2006). In some cases, priorities based on the train type or the service provided to the passengers are also considered in the objective function (Caprara et al., 2011; Corman et al., 2016; Dollevoet et al., 2014; Lamorgese and Mannino, 2015; Lusby et al., 2013; Törnquist and Persson, 2007).

Two different granularities are mainly used to model the infrastructure elements when tackling the rtRTMP: *macroscopic*, where each resource corresponds to groups of block-sections (Dessouky et al., 2006; Kecman et al., 2013; Sahana et al., 2014; Törnquist and Persson, 2007; Veelenturf et al., 2016), and *microscopic*, where each resource corresponds to a single block-section (Acuna-Agost et al., 2011; Corman et al., 2010; D'Ariano et al., 2007; Mazzarello and Ottaviani, 2007; Samà et al., 2017) or track-circuit (Caimi et al., 2012; Lusby et al., 2013; Pellegrini et al., 2014; Rodriguez, 2007). These two granularities may be used concurrently to model different parts of the infrastructure, e.g., macroscopic lines and microscopic stations (Lamorgese and Mannino, 2015).

The rtRTMP is NP-Hard. Typically, the size of its search space is strongly affected by the number of alternative routings available for each train (Samà et al., 2016). Various approaches limit the number of routing variables in order to simplify the solution process. Some approaches utilize the routing chosen in the timetable to compute an initial solution to use as upper bound for the rest of the solution process (Corman et al., 2010; D'Ariano et al., 2008; Pellegrini et al., 2014; Pellegrini et al., 2015; Samà et al., 2017). Others carefully select a routing for each train among the possible alternatives before taking the train ordering and timing decisions (Caimi et al., 2011; Rodriguez, 2007). In Caimi et al. (2012), the routing decisions are combined with the timing decisions in the form of train speed-profiles, defining a few blocking-time stairways (Hansen and Pachl, 2014) among which the final solution is built. In Mu and Dessouky (2011), the problem is modeled macroscopically and it is assumed that each track can be traversed in one direction only, associating a track occupation variable to each possible train-track pair and checking the coherence of the routing chosen through flow conservation constraints. In Meng and Zhou (2014), the number of routing variables is limited by considering in a macroscopic model simultaneous timing and routing decisions, through cumulative flow variables instead of binary variables. Another common practice is to fix the train routing as the one chosen during the timetable computation (Corman et al., 2011; Corman et al., 2014; D'Ariano et al., 2007; Liu and Kozan, 2009; Mladenovic et al., 2016; Meng and Zhou, 2011; Törnquist Krasemann, 2012). Typically, the rtRTMP solution approaches presented in literature do not consider all the alternative routings available for the trains.

The Train Routing Selection Problem (TRSP) defines a routing subset for each train so that feasible combinations of train routings exist which allow the construction of good quality solutions, without having to simultaneously consider timing and ordering decisions. The subsets obtained as the result of the TRSP are then used during the solution of the rtRTMP.

A common practice to tackle the TRSP is to select routings by following directives of the infrastructure managers. Initial attempts to solve the problem were based on a priori (Caimi et al., 2011) or random decisions (Pellegrini et al., 2015). The first formalization of the TRSP has been done in Samà et al. (2016). The latter paper proposes a mixed integer linear programming formulation for the TRSP, together with a method to evaluate the possible influence that the choice of a particular routing may have on the rtRTMP solutions quality. Furthermore, it provides an algorithm to solve the TRSP, based on Ant Colony Optimization (ACO) (Dorigo and Stützle, 2004), and highlights the benefit that solving the TRSP has on the rtRTMP solution process.

As far as we know, this paper addresses for the first time the question wondering when the best moment to perform the selection may be. To this aim, two alternatives are considered:

Solving the TRSP at tactical level. The TRSP in this case integrates the tactical timetable and the operational rtRTMP. The selection is based on records of past perturbed traffic. There are no particular restrictions on the maximum computation time to allocate to the solution process. For each train, its available routings are sorted based on how frequently they are selected given the different traffic perturbation records. The routing subsets are then selected for each specific perturbation, including the p feasible ones which were most frequently selected in the traffic perturbation records. These routings are used by the rtRTMP solver.