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Ant colony optimization for the real-time train routing selection problem

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ABSTRACT

This paper deals with the real-time problem of scheduling and routing trains in a railway network. In the related literature, this problem is usually solved starting from a subset of routing alternatives and computing the near-optimal solution of the simplified routing problem. We study how to select the best subset of routing alternatives for each train among all possible alternatives. The real-time train routing selection problem is formulated as an integer linear programming formulation and solved via an algorithm inspired by the ant colonies' behavior. The real-time railway traffic management problem takes as input the best subset of routing alternatives and is solved as a mixed-integer linear program. The proposed methodology is tested on two practical case studies of the French railway infrastructure: the Lille terminal station area and the Rouen line. The computational experiments are based on several practical disturbed scenarios. Our methodology allows the improvement of the state of the art in terms of the minimization of train consecutive delays. The improvement is around 22% for the Rouen instances and around 56% for the Lille instances.

1. Introduction

In the last decade, traffic demand in transports in general and railways in particular has significantly grown. To appropriately address this growth, railway undertakings and infrastructure managers face the challenge of expanding their offer. The difficulties in building new infrastructures due to high costs or physical obstacles translate into the need to utilize the already existing ones at their full capacity. To maintain a satisfactory quality of service and reduce passengers' inconvenience (Ginkel and Schöbel, 2007), it is necessary to manage precisely and efficiently the railway traffic in case of unexpected disturbances and disruptions that may affect the normal course of daily operations. Still, few decision support tools are available to help dispatchers in minimizing the impact of these events. Currently, dispatchers intervene manually in real-time, sometimes using pre-made contingency plans that, while helpful, cannot cover all the potential scenarios that may occur. Indeed, it is not easy to immediately judge the effects a particular decision may have. Solving a single event as best

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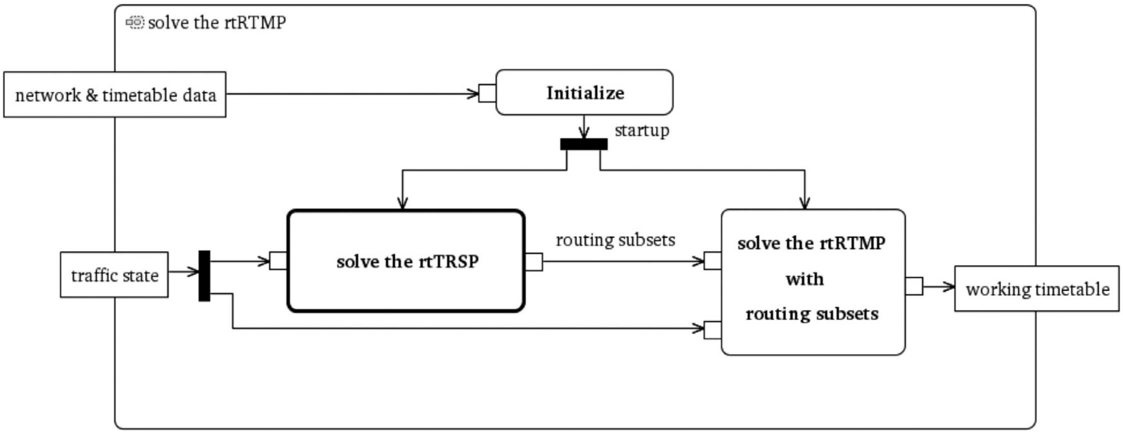

Fig. 1. SysML activity diagram representing how to solve the rtRTMP.

as possible could actually not be the most appropriate decision when considering traffic with a broader perspective. In fact, such a decision may indirectly generate further disturbances, propagating the delay in a snow ball effect.

The real-time Railway Traffic Management Problem (rtRTMP) is the problem of detecting and solving conflicting track requests by multiple trains during disturbed operations (Pellegrini et al., 2014). The rtRTMP is an NP-Hard problem where routing, ordering and timing decisions are made simultaneously. Moreover, the characteristics of the railway infrastructure and of the traffic flows, and in particular the number of routing alternatives for each train, strongly affects the time required to compute good quality solutions (Pellegrini et al., 2015).

Recent literature reviews show a rich stream of research focused on the rtRTMP (Cacchiani et al., 2014; Corman and Meng, 2015; Fang et al., 2015). Most of the existing approaches do not consider all set of possible routing alternatives present in the infrastructure for each train. A subset of routing alternatives is very often considered in the rtRTMP optimization. This subset is usually defined by taking into account the suggestions given by the dispatchers and by considering alternative routings similar to the one defined in the timetable. This is a reasonable assumption since the rtRTMP needs to be solved in real-time. However, the resulting rtRTMP optimization is a simplified routing problem and the computation of near-optimal solutions for the simplified problem does not necessarily correspond to near-optimal solutions for the original rtRTMP.

This paper studies the under-investigated problem of selecting the best subset of routing alternatives for each train among all possible alternatives. We call this problem the real-time Train Routing Selection Problem (rtTRSP). Fig. 1 shows a SysML activity diagram (SysML, 2015) in which the relation between the rtRTMP and rtTRSP solution activities is depicted. An activity diagram describes the sequence of actions to be performed to transform inputs into outputs. These inputs and outputs are represented as rectangles spanning the activity frame boundary. The actions are represented as rounded rectangles. An action begins as soon as all its required inputs are provided. In general, the rtTRSP is a subproblem of the rtRTMP: the rtTRSP solution allows the reduction of the size of the rtRTMP search space, which shall then be solved on the reduced space through one of the approaches existing in the literature. The input required to solve the rtRTMP are data on the infrastructure, the timetable and the traffic state at a reference time. The data on the network and the timetable are used to initialize both the "solve the rtTRSP" and the "solve the rtRTMP with the routing subsets" actions. After the initialization, the traffic state at a reference time is provided in order to perform the "solve the rtTRSP" activity by taking into account the current traffic information. This input is transmitted concurrently to the "solve the rtTRSP" and the "solve the rtRTMP with the routing subsets" actions. However, the latter can start only after the end of the former, since the required input "routing subsets" needs to be computed beforehand. The final output produced is a new working timetable, which includes all routing, ordering and timing information to be used in the operations.

The common practice of solving the rtTRSP is to follow some pre-determined directives given by the infrastructure managers on which routing subset should be considered for each train in real-time in order to help dispatchers when dealing with traffic disturbances. These directives are too general, while a case-to-case solution is required during operations. A dynamic selection of the routing subsets may intuitively improve the quality of the rtRTMP solution. However, the definition of the routing subsets requires to address the following trade-off. On the one hand, considering small subsets of all possible train routing decisions would reduce the number of variables to be tackled in the rtRTMP, and increasing the chances of finding good quality solutions in a short computation time. On the other hand, considering large subsets would increase the probability of preserving the optimal mix of train routings in the search space of the rtRTMP, but finding the global optimum may require a too high computation time.

This paper presents a general methodology to tackle the rtTRSP based on the scheme of Fig. 1. We propose an integer linear programming formulation of the rtTRSP with the objective of finding a good quality routing subset for each train, where the subset quality is defined as a function of the interactions among the routings selected for trains traveling in the infrastructure. Since a solution to the rtTRSP needs to be computed very quickly and the search space contains a very large