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A decomposition approach for the real time Railway Traffic Management Problem

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In critical points and at rush hours, the traffic in the rail network is often very heavy. Hence, when a disruption occurs and the traffic is perturbed, conflicts may emerge: two or more trains traveling at the planned speed would claim the same portion of track concurrently. In case of conflict, some trains must be stopped or decelerated for ensuring safety, and delays propagate. The real-time Railway Traffic Management Problem (rtRTMP) aims to modify trains route and schedule to limit delay propagation in the network. In the practice, this problem is tackled by dispatchers. They tackle it manually, so the result of their choices is generally suboptimal. The use of an efficient algorithm to support dispatchers decision making is crucial to ensure an effective traffic management when disruptions occur. The design of this efficient algorithm is typically based on two mains models used to represent the railway infrastructure: macroscopic and microscopic. In the macroscopic model, the infrastructure is seen as a set of nodes (junctions or stations) connected by lines, and the separation between trains is imposed through the control of generic headway times. In the microscopic one, the infrastructure is seen as a set of track sections where the train separation is imposed according to the signaling system, as it happens in reality. With the former, we can solve very large instances, but with low precision at the local level; hence, the optimization choices may have unexpected effects on the traffic when they are actually implemented, due for example to the specific signaling system in place. With the latter, these unexpected effects are avoided by considering in the optimization all necessary details. However, solving large instances may become very difficult due to memory or computational time limits.

In the rtRTMP literature, few papers deal with the need of tackling very large instances microscopically by using a decomposition method. Some papers, as [1], propose heuristic approaches to decompose the instances to be solved. The authors decompose large instances of the rtRTMP by dispatching areas and apply a bi-level optimization approach to solve the problem. At the lower level, dispatchers manage traffic in their control areas without any knowledge of the traffic flow elsewhere. At the higher level, coordinators are responsible for the traffic management over a railway network including several areas with a global vision of the traffic flows. Others, as [2], propose classic decomposition approaches as column generation. This column generation approach is applied to a set packing model to tackle real time train routing at junctions. The set packing model of the problem is formulated as an integer linear program with a resource based constraint system. A Benders decomposition approach is proposed by [3] to solve the rtRTMP. In the paper, the authors combine a macroscopic and a microscopic model to perform a decomposition of the initial problem into two subproblems (master and slave problem). This approach allows dealing with instances representing a big infrastructure but it does not consider the actual details on the microscopic infrastructure characteristics. In this paper, we propose a Benders algorithm applied to a model considering all these microscopic characteristics. We use as the model to be decomposed the mixed integer linear programming formulation RECIFE-MILP, proposed by [4].

In our Benders algorithm train routing and scheduling decisions are made in the master problem. Given these decisions, we compute the trains actual arrival times in the dual of the slave problem to deduce the total delay. Based on the result of the dual, we add an optimality or feasibility cut to the master problem to cut off the current solution, if suboptimal or infeasible for the overall problem. This process is repeated until the algorithm converges to an optimal solution or a maximum computational time imposed by the real-time nature of the problem has elapsed.

We assess the performance of our Benders algorithm with respect to the RECIFE-MILP algorithm of [4]. We consider a case-study representing traffic in the Rouen-Rive-Droite control area to run our experiments. This case-study is recognized to be difficult to tackle in the time limit imposed by the rtRTMP [4]. We set the computational time available for the optimization to five minutes. The implementation is done using IBM ILOG CPLEX Concert Technology for C++ (IBM ILOG CPLEX version 12.6 [5]).

We consider a one-day timetable, and we create 100 random scenarios: 20% of trains, randomly selected, suffer a random delay between 5 and 15 minutes at their entrance in the control area. We generate one rtRTMP instance from each of these 100 scenarios by considering all the trains entering the control area within an hour horizon. We set the time horizon from 6:00 am to 07:00 am. This time horizon corresponds to the morning peak hour. The so obtained one-hour instances include between 10 and 13 trains (mean 11). Each train can use between 1 and 192 routes (mean 45).

The results show that the RECIFE-MILP algorithm achieves the best performance for more cases than the Benders algorithm: 96 versus 4. For the instances on which the Benders algorithm is the best, we discover that the percentage of optimality cuts with respect to the total number of Benders cuts is very high: 97% in average. Instead, when the RECIFE-MILP algorithm is the best, we remark that this percentage decreases: 85% in average. Hence, we conjecture that the performance of the Benders algorithm would improve if the percentage of the optimality cuts generated during the Benders iterations increased. In a future work, we will focus on how to generate strong valid inequalities in the Benders master problem. These inequalities must make the dual of the Benders sub-problem bounded and warrant the generation of the optimality cuts.

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