A Matheuristic for Solving the Locomotive Scheduling Problem with Maintenance Constraints for the Rail Cargo Austria

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Abstract

The Locomotive Scheduling Problem (LSP) plays a crucial role in the railway industry. The aim is to assign a fleet of locomotives to a set of scheduled trains such that the overall costs are minimized, while several assignment restrictions and operational requirements are met. As the rolling stock represents one of the main costs, this is a key challenge of a rail company. We formulate this optimization problem on a sparse weighted directed multi-graph. Based hereon we propose a Mixed-Integer Linear Program (MILP) that scales well and delivers optimal solutions for many LSP instances in freight transportation in reasonable time. However, in practical applications, maintenances for the rolling stock are of central importance. Thus, we adapt our model by introducing the required maintenance constraints, now speaking of an LSP with maintenances (LSPM). With increasing complexity our adapted MILP becomes intractable even for small instances, making an alternative solution approach necessary.

In this talk we present an efficient two stage approach that yields high-quality locomotive assignments implementable in real-life. In the first stage, an optimal solution for the related LSP is determined by solving the MILP. In the second stage, a heuristic procedure is applied to iteratively resolve maintenance violations. We evaluate our approach using instances generated based on real-world data provided by Rail Cargo Austria, the largest rail company for freight transportation in Austria and one of the largest in Europe.

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1. Problem Formulation

The Locomotive Scheduling Problem with Maintenances (LSPM) consists of finding the most cost efficient assignment of a fleet of locomotives to a set of scheduled trains. It must be assured that each scheduled trip is served, while several assignment restrictions and maintenance constraints are satisfied. In Frisch et al. (2019) we propose a multi-graph model and formulate a Mixed-Integer Linear Program (MILP) for solving the LSPM. A very simple example is illustrated in Figure 1. For the exact mathematical formulation we refer to Frisch et al. (2019).

In our former work, we minimized over the number of locomotives used and the total number of deadhead kilometers driven and evaluated the MILP on synthetic data. In contrast, we now aim to minimize the overall operational costs of the rolling stock for the Rail Cargo Austria (RCA). Doing so, we minimize over the total costs for deployed

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locomotives, deadhead and scheduled kilometers, and realized maintenances, using reasonable monetary costs as weights.

Fig. 1. Simple problem graph on the left hand side. We have two locomotive start nodes, three scheduled trips and an artificial final node where all locomotives have to end up. Arcs are weighted by the corresponding distances. Arcs for deadhead trips are dotted arrows and arcs for maintenances are dashed arrows. Note that each maintenance arc is related to a certain locomotive. Dark gray nodes display possible maintenance points. For reasons of clarity all arcs to the final node are omitted in the problem graph. One feasible solution is depicted in the solution graph on the right hand side. Unused arcs are light gray.

2. Heuristic Procedure

We propose an efficient solution approach that combines a heuristic with our MILP formulations. The algorithm consists of two stages. In the first stage we determine the optimal solution for the basic LSP (without considering maintenance constraints) by solving the MILP. In the second stage we iteratively resolve maintenance violations of the locomotive assignments obtained in stage one.

Based on the solution of stage one, we continue with introducing the following sets. We consider the set of locomotive assignments violating required maintenance restrictions by \( A_{\text{vio}} \) := \((L_{\text{vio}}, S) := (L, S_L)_{L \in L_{\text{vio}}}, \) where \( L_{\text{vio}} \) denotes the set of locomotives showing maintenance violations and \( S \) contains all scheduled trips involved. Furthermore, we collect all remaining available locomotives that are not assigned to any scheduled trip, in \( L_{\text{av}} \) and unite empty assignments in \( A_e := (L, \emptyset)_{L \in L_{\text{av}}}. \)

For each assignment in \( A_{\text{vio}}, \) we first try to include a maintenance as close as possible at the limit of allowed traveled kilometers. If the inclusion is successful, we remove the resolved assignment. If not, we incrementally drop out scheduled trips from the concerned assignment and allocate them to appropriate locomotives in \( A_e, \) until a maintenance can be inserted. Again, we remove the resolved assignments. Once the cardinality of \( A_{\text{vio}} \) reaches a certain small enough size, we stop and solve the remaining LSPM instance, consisting of \( A_{\text{vio}} \) and \( A_e \) (now containing several trips), to optimality with our MILP. In order to reduce the number of variables in the MILP, we additionally set look ahead time restrictions for maintenance arcs, i.e., we only include possible ways for deadhead trips with maintenances if the time distance does not exceed a predefined maximum value. Concerning the restriction of the solution space, this value must be chosen carefully.

We perform a comprehensive evaluation with instances generated on real-world data provided by Rail Cargo Austria (RCA). Weights in the objective are chosen as reasonable monetary costs for each component. The proposed matheuristic yields high-quality results for instances up to 2500 trips, while requiring only little computation time.

References