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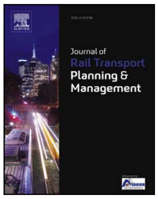

Resource considerations for integrated planning of railway traffic and maintenance windows

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A R T I C L E I N F O

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A B S T R A C T

This paper addresses the coordination of railway network maintenance and train traffic. The work extends a previously developed optimization model by considering maintenance resource constraints for crew availability and work time regulations. The aim is to find a long term tactical plan that minimizes the total cost of maintenance and train operations, where train services and train free windows are scheduled such that maintenance can be carried out by a pool of crew resources, which are divided into bases and have limitations on maximum working hours per day and minimum rest time between these working days. A mixed integer linear programming model along with computational experiments are presented which show that these resource considerations can be correctly handled with a moderate increase in model size and solution time.

1. Introduction

Railway infrastructure maintenance consumes large budgets, is complicated to organize and has numerous challenging planning problems. Specifically, the coordination of maintenance tasks and train traffic is of great importance, since these activities are mutually exclusive. This planning conflict becomes crucial on lines with high traffic density and/or around the clock operation — especially when both traffic demand and maintenance needs are increasing.

We address the problem of how to coordinate network maintenance and train services on a common railway infrastructure. The objective is to achieve a long-term tactical master plan for when and how to perform traffic and maintenance, by scheduling train paths as well as train free time windows where maintenance work can be carried out, such that the total cost for maintenance and train operations is minimized. An aggregated approach (both spatial and temporal) is used, which assumes that the detailed train conflict resolution (meet/pass planning) is handled in a subsequent timetabling process step. A basic model that solves this coordination problem to optimality has been presented in Lidén and Joborn (2017), where a complete description of the background, problem setting, relevant research literature and model details can be found.

This paper extends the previous work by considering maintenance resource constraints and costs. The resource constraints ensure that the obtained scheduling of maintenance windows can be covered by a pool of crew resources, which are divided into bases and have limitations on maximum working hours per day and minimum rest time between these working days.

The contributions of this work are: (1) showing how some important crew resource considerations can be modelled, and (2) computational experiments demonstrating the effect of including these aspects in the optimization model. To the best of our knowledge, this is the first research publication that jointly schedules both train services and time for network maintenance, while

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considering crucial maintenance resource limitations.

The paper is organised as follows: Section 2 describes the problem setting and features considered. Section 3 gives a brief overview of related research. The mathematical model is presented in Section 4, followed by the computational experiments and results in Section 5. Finally, some concluding remarks are given in Section 6.

2. Problem description

The planning problem we consider applies to organisations that are responsible for coordinating railway traffic and network maintenance slots, such as infrastructure managers, transport administrators or railway companies that own and operate the infrastructure network. The planning horizons of train services and maintenance tasks can differ substantially, which — depending on the planning procedure — may favour early applicants and leave costly or even insufficient track access possibilities for other actors. This situation has been observed in Sweden where the increase in rail traffic together with the current planning regime has forced maintenance to be performed on odd times and/or in shorter time slots which leads to inefficiency and cost increases for the maintenance contractors, potentially even reduced track quality, leading to an increase in governmental spending.

To increase the possibility of suitable work possessions, a new planning regime is being introduced, where the Swedish Transport Administration propose regular, 2–6 h train free maintenance windows *before* the timetable is constructed. The maintenance windows are given as a prerequisite for: (a) the procurement of multi-year maintenance contracts, and (b) the yearly timetable process, which give stable quotation and planning conditions for the contractors. The overall aim is to increase efficiency, reduce cost and planning burden as well as to improve robustness and punctuality. However, since maintenance windows will reduce the train scheduling possibilities, the window patterns should be designed such that maintenance activities and train operation is coordinated in a well-balanced manner, which is non-trivial.

We address the coordination of maintenance windows and train traffic as an optimization problem for a railway infrastructure network. The purpose of the optimization model is to find a pattern of maintenance windows that allows a desired set of train services to be run and that minimizes the total cost for train operations and maintenance. The train operating cost is measured by total running time, deviation from preferred departure, route choice and cancellations, while the maintenance cost consists of direct work time, indirect setup/overhead time and crew costs. Routing and scheduling of trains respect given minimum travel and dwelling durations as well as the line capacity limitations imposed by the maintenance scheduling. The maintenance window schedule fulfills given work volumes, where the number of windows and their temporal size respect a chosen window option for each network link as well as maintenance resource considerations.

A macroscopic infrastructure model is used, which allows for networks of arbitrary size and granularity. Nodes are placed where train services start, end or may change route, as well as between different maintenance areas. The nodes are connected by links which correspond to single, double or multi-track lines that may contain intermediate stations (meet/pass loops). Traffic capacity restrictions are modelled as limitations on the number of trains that can be scheduled over each link per time period, both in each direction and as a sum of both directions. The traffic capacity is reduced when maintenance windows are scheduled on the links.

Throughout this paper we use the term *crew* for a potential work group, which may consist of several people and necessary equipment. We only distinguish the crew resources by the links they can service. Thus the model does not consider different resource types and whether a maintenance window should be used for a specific type of maintenance activity. Also, it should be noted that the model is not intended for scheduling actual maintenance tasks — rather it aims at constructing train free windows that give an optimal balance between train operating and network maintenance costs, in a way that can be efficiently utilized by the maintenance contractors.

Although it is the responsibility of the contractor to manage the maintenance resources, the design of the window patterns together with the partitioning into contract areas will determine the possible crew scheduling and subsequently the number of maintenance crew needed. In general, simultaneous windows will increase the crew demand while sequential windows on neighbouring links enable the contractor to cover several windows with the same crew during a working day. Thus the major resource driving aspects should be considered (by the infrastructure manager) when constructing the maintenance windows, since they will impact the maintenance/contractual cost. The resource considerations to include in our model have been discussed and agreed upon with the Swedish Transport Administration and one of the major maintenance contractor companies.

The first type of resource consideration is the number of crew per maintenance base and the links they can service, which constrains the number of concurrent maintenance windows that can be scheduled. The number of crew may also be unlimited along with a cost for each crew utilized, in which case the model should choose the optimal combination of crew, window and train scheduling. Since we have no distinction between resource types, all crew within one base can serve the same set of links. The crew bases may overlap, i.e. certain links may be serviced by more than one base. By varying the base configuration it is possible to evaluate and experiment with different contract areas and partitions.

The second type of maintenance crew resource consideration is work time regulations, given as maximum number of work hours per working day (typically 8–12 h) and minimum rest time between working days (typically 10–16 h). The exact start/end time of the working days need not be given beforehand, but is left for the optimization model to decide.

Finally we note that in this work exactly one crew is assigned to each maintenance window. It might however be interesting to include requirements on the number of crews that should be assigned to each maintenance window.

We end this section by summarizing the problem features and giving some typical properties. First of all, both maintenance windows and train services are to be scheduled over a railway network for a period of one or more days. The tasks are typically one to a couple of hours long, where the train services have continuous (real-valued) start/end times and durations over the links. The track