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An optimization model for integrated planning of railway traffic and network maintenance ☆

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ABSTRACT

Railway transportation systems are important for society and have many challenging and important planning problems. Train services as well as maintenance of a railway network need to be scheduled efficiently, but have mostly been treated as two separate planning problems. Since these activities are mutually exclusive they must be coordinated and should ideally be planned together. In this paper we present a mixed integer programming model for solving an integrated railway traffic and network maintenance problem. The aim is to find a long term tactical plan that optimally schedules train free windows sufficient for a given volume of regular maintenance together with the wanted train traffic. A spatial and temporal aggregation is used for controlling the available network capacity. The properties of the proposed model are analyzed and computational experiments on various synthetic problem instances are reported. Model extensions and possible modifications are discussed as well as future research directions.

1. Introduction

Efficiency in public and freight transportation systems is of great importance for a society. Railways can offer high capacity and relatively low environmental impact, but require that several technical systems like the track, power distribution, safety, telecommunications and trains are tuned and operate well. Disturbances in any of these systems will degrade the service level. Moreover, failures or degradation in one may cause damages in the others, which is particularly true for track, trains and power distribution. Thus, maintenance is essential for upholding reliability, transportation throughput and the benefits of the infrastructure system investments.

Railway infrastructure maintenance consumes very large budgets, is complicated to organize and has numerous challenging planning problems (Lidén, 2015). 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, which is the case in many European countries. Hence, large benefits can be realized if planning, scheduling and effectuation can be improved. As an example of monetary volumes, the European countries are reported to allocate 15–25 billion EUR annually on maintenance and renewals for their railway systems consisting of about 300,000 km of track, giving an average spending of 70,000 EUR per km track and year (EIM-EFRTC-CER Working Group, 2012). The spending in Sweden is in the same range: During the year 2014 a budget of 910 million EUR was used for a track network of 14,700 km. At the same time the major

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passenger traffic operator (SJ AB) and freight traffic operator (Green Cargo AB) had a joint turnover of 1465 million EUR. Thus the maintenance spending amounts to about 60% of the main traffic operator costs.

Historically, research about railway scheduling and planning has focused mainly on train operations and timetabling. In such models, maintenance activities can be handled as fictitious slow-moving trains. Kraay and Harker (1995) and Törnquist Krasemann (2015) (both of which treat real-time operational dispatching) mention this possibility, without discussing it further. This is a valid approach if the work tasks to be scheduled have a fixed duration and do not impose other restrictions than the blocking of one track section. It is however not sufficient for situations where (a) a work activity can be interrupted (for letting real trains through), (b) the work closes off several tracks or line segments at the same time, or (c) the work inflicts speed restrictions or other operational restrictions on neighboring tracks. In such cases maintenance should be treated as separate planning objects, since the interaction between traffic and maintenance can be modeled more correctly. In addition, the following properties distinguish maintenance from traffic: (i) work tasks can be co-located, (ii) the costs have a non-linear dependency on the given shift and possession time and (iii) work force restrictions are differently handled.

Maintenance can also be considered as orthogonal to train traffic, since the former is mainly tied to and organized in bounded geographical areas, while train traffic concerns transportation needs between distant regions. Consequentially, the responsibility for traffic and infrastructure is usually split into separate organisations or companies. Thus the planning tasks are also divided - each party treating the other type of activities as an unknown or given input - and solving the track access (capacity) conflicts with some coordination or resolution procedure. Not surprising, there is often a lack of understanding and even mistrust between representatives for traffic operators, infrastructure management and contractors. This situation will almost certainly result in solutions that are less good or even inefficient for one or more of the parties.

In summary, the volumes, importance and specific properties of railway infrastructure maintenance give strong motivations for investigating how maintenance activities and traffic operation could be planned together efficiently. Further, there has been very little research about how to model or solve such integrated planning problems.

The research question addressed in this paper is how to coordinate maintenance activities and timetabled traffic operation on a common railway infrastructure. The hypothesis is that this coordination problem is possible to model and solve as an optimization problem. We will investigate how well a mixed integer linear programming approach is able to capture and solve the studied planning problem. The aim is to achieve a long term tactical 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.

The contributions of this work are: (1) the formulation of a mixed integer optimization model which jointly schedules train services and windows for infrastructure maintenance and (2) experiments demonstrating that weekly network problems and 1–2 day long line problems can be solved to near optimality within one hour of computation for synthetic test instances. The model uses an aggregated approach both spatially and temporally and the problem size is shown to grow linearly with the planning horizon if the train scheduling windows are limited.

The purpose of the optimization problem is to find a pattern of maintenance windows that allows for a wanted train traffic 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 cost and cancelations, while the maintenance cost consists of direct work time and indirect setup/overhead time. Routing and scheduling of trains will respect given minimum travel and dwelling durations as well as the line capacity limitations imposed by the maintenance scheduling. Sufficient amount of maintenance windows will be scheduled to fulfill a given work volume, where the number of windows and their temporal size will respect a chosen window option for each network link. The main aspects, which are not considered in the presented model are: (i) train and maintenance resource constraints, (ii) regularity requirements and (iii) the detailed meet/pass planning needed for a conflict-free timetable.

The remainder of the paper is organized as follows: The problem setting together with basic assumptions and delimitations are presented in Section 2 followed by a literature review in Section 3. We then introduce and describe the optimization model in Section 4, while the complete and detailed mathematical notation is given in Appendix A. Computational experiments on a set of generated test instances are presented in Section 5 after which the model is discussed along with possible modifications, extensions and alternate approaches in Section 6. Conclusions and possible continuations are presented in Section 7. Finally, Appendix B lists the number of variables and constraints needed for the model and in Appendix C all the detailed computational results are given.

2. Problem setting

As a background we cite a previous paper (Lidén and Joborn, 2016):

> All non-train activities that require secure access to the railway infrastructure must obtain a (work) **possession** (RailNetEurope, 2013). Up to now, the planning regime adopted in Sweden has been to let the maintenance contractors apply for these work slots, which usually is done as late as possible. If no room is reserved for maintenance in the timetable it can be difficult to find suitable possessions, which forces the contractors to perform their work on odd times and/or divide the tasks into small chunks which leads to inefficiency and cost increases. If the work cannot be split into smaller tasks, then the timetable must be altered and train operations rescheduled. [..]
> To increase the possibility for suitable work possessions, a new planning regime is now being introduced in Sweden, called **maintenance windows**, where the infrastructure manager will propose regular, 2–6 h train free slots *before* the