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Models for railway timetable optimization: Applicability and applications in practice

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A B S T R A C T

This paper provides an overview of railway timetable design in practice and the combinatorial optimization models that have been proposed for this application, putting emphasis on passenger railway services in the European railway market.
We start with a description of the role of the timetable for a railway system, including the perspective of both types of railway companies: train operating companies (TOC) and infrastructure managing companies. We elaborate on the different subprocesses in timetable design that have to be conducted, some of which are exclusive to TOCs, while others are in the responsibility of the infrastructure manager.
The two major streams of combinatorial optimization models for railway timetabling must not be understood as concurring models. Rather, they address different subprocesses, even with a focus on different types of railway companies. In this paper we provide a comparison of the different approaches on a number of relevant criteria.
Having sketched the major streams we list methods that have been developed for improving the robustness of timetables, including stochastic optimization models and light robustness models. We also provide a description of a number of applications of timetable planning models in practice. We conclude this paper with some topics for further research.

1. Introduction

We dedicate this paper to Leo, who unfortunately passed away much too soon!

Railway operations research is dealing with timetables in many aspects. Based on an appropriate infrastructure modeling and running time estimates, the timetable is actually designed, i.e. the train paths are specified with respect to time and space. Then, the timetable may be evaluated by the use of analytical and/or simulation methods in order to assess its robustness (e.g. by empirically measuring its punctuality with respect to some perturbations), which is a major performance indicator. Finally, during operations complex rescheduling measures may have to be applied to the scheduled timetable, see Fig. 1 for an

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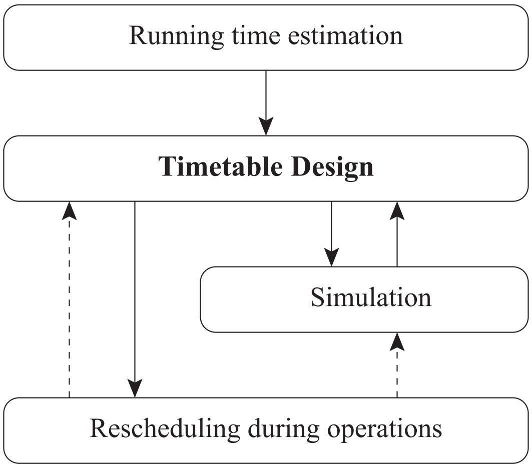

Fig. 1. Schematic workflow of selected topics in railway operations research.

overview. For a comprehensive treatment of this variety of all the challenging timetable aspects in railway operations research, we refer the interested reader to Hansen and Pachl (2014).

In this paper we concentrate on the design of timetables. As we might discover, even this single planning aspect reveals a certain variety of subproblems, even requiring different combinatorial optimization models for solving these problems. Until recently, the railway timetabling process was carried out mainly manually, based on the experience and craftsmanship of timetable planners. However, due to strong improvements in the computational power of computer hardware and in the available optimization algorithms, nowadays several automated railway timetabling systems are available and used in practice. The timetables of several European railway companies have been computed using Operations Research techniques (see Section 6), the timetables of all of these example networks being periodic.

These applications in practice often lead to challenging new research questions. Therefore, railway timetabling is currently a highly active and relevant research area. Though, well-established commercial software kits as they exist for running time estimation or simulation (such as OpenTrack, 2016 and RailSys RMCon, 2016), so far are not available for an optimized actual design of the timetable for a railway network. In addition to our discussion in Section 2, we suppose that the following point is part of the explanation: In particular for passenger services, since the timetable defines infrastructure usage and travel times for the passengers, any software tool has to model these two streams at a significant level of detail – yet we are not aware of any software tool that has an intrinsic data model for both.

Note that we consider timetabling mainly as a kind of scheduling problem. Some authors include aspects of network design and routing into their contributions to timetabling, mainly at the price of the problem size that can be solved to optimality. Our focus, however, is on coming up with timetables for entire networks. Therefore, we assume a fixed infrastructure, and do not consider possible track extensions. Nor do we consider any alternatives for the detailed routing, unless stated otherwise. This applies to both the routing of the passengers as well as the routing of the trains through the network. We refer to Cacchiani and Toth (2012), Lusby et al. (2011), and Harrod (2012) for other recent overviews of research on railway timetable optimization. These papers focus on the mathematical models, whereas the current paper focuses on the practical applicability of the described models.

This paper is structured as follows. In Section 2 we describe some general characteristics of a railway timetable. We also describe the planning process that is carried out within the involved railway companies to arrive at the published timetable. This background knowledge on the planning process is key for a good understanding of the remainder of this paper. In Section 3 we describe different types of timetables, from timetables with individually scheduled trips to integrated fixed interval timetables. In Section 4, we survey optimization models that had been proposed in the literature for computing annual working timetables. In particular, we shortly elaborate on the techniques that are available for generating periodic timetables, but also compare the various approaches with respect to relevant criteria. Then, in Section 5, we describe references to model extensions that aim at improving the robustness of a timetable. A number of practical applications are provided in Section 6. We close the paper with a number of conclusions and suggestions for further research in Section 7.

2. The timetable

The timetable is an important concept in a railway system. On the one hand, it describes the product that is offered to the customers: the passengers and the cargo forwarders. These are mainly interested in the departure and arrival times of the trains in the stations and in the number of transfers. On the other hand, the timetable also contains elements that are needed for guaranteeing its feasibility: the passing times of the trains at relevant underway locations such as bridges and junctions,