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Automatic generation of railway timetables based on a mesoscopic infrastructure model

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ABSTRACT

This paper presents a large-scale application of a heuristic timetabling algorithm on a mesoscopic description of the railway network infrastructures.

We consider a mesoscopic model as it allows a significantly higher accuracy compared to the macroscopic models used in many scientific works. Specifically our mesoscopic model allows an estimation of the headway times and of the conflicts on lines and stations as well as a calculation of running times and time-losses performed with the same detail enabled by simulation models. In addition, in order to maximize the accuracy in the definition of the timetable, various parameters can be defined for each train, including the buffer times, the priority and the allowances.

The model is applied to the rail network of the North-East of Italy. It is tested under different demand conditions, for example considering an increase of the demand for freight slots or a different structure of regional services. Moreover, it is used to obtain a rough estimate of the maximum capacity for freight trains combined to fixed passenger services and the effects of infrastructure improvements.

1. Introduction

In this work, we introduce a heuristic solution approach to the Train Timetabling Problem (TTP) for large-scale railway networks when they are described at mesoscopic level.

The TTP is an NP-hard problem that aims at determining, for a given set of trains, the arrival and departure time at each of the stations the train visits along its route (see, e.g., Hansen and Pachl 2008). The TTP is an interesting problem from a practical point as the timetable represents a key element for the competitiveness of railways, since it allows exploiting the existing infrastructures at their maximum. In the recent years, the importance of an optimal usage of these infrastructures is, if possible, even increased due to the progressive deregulation of the market. Different operators are now competing for the access to the same generally scarce resources and many conflicts may arise (Cacchiani et al. 2008) and must be solved through a sensible timetabling.

Our heuristic is based on a multicommodity flow model and aims at realizing timetables that exploit the capacities of the networks and ensure suitable travel times for the passengers. It also aims at generating timetables that can be immediately accepted by the human planners and applicable to real-world situations, with only minor adjustments. To satisfy the first set of requirements, our heuristic considers as objective the minimization of the overall penalties paid for each train not inserted in the final timetable and for each train whose schedule differs from the desired one. These last penalties include the ones paid for not respecting scheduling constraints, e.g., about the connection with other trains. In addition, given the advantages and disadvantages of symmetry in timetables, our heuristic also manages the possibility of imposing symmetric return trips, if required by the user.

To satisfy the second set of requirements our heuristic needs as input a precise estimation of blocking times. In turn, these values must be based on an accurate assessment of running, dwell and headway times and must take into account the signal spacing and train processing at critical route nodes and platform tracks (Hansen 2010; Quaglietta 2013), where a deep analysis of the relationship between the quality of a timetable – expressed in terms of arrival delays and energy consumption – and the characteristics of the infrastructure, the headways and dwell times is presented). For these reasons we provide as input to our heuristic a mesoscopic description of the infrastructures of the railway network of interest. This kind of description allows a significantly higher accuracy compared to the macroscopic models used in most scientific work. Specifically, it allows an automatic estimation of the line headway times and of the blocking times within stations. Moreover, it

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returns running times and time-losses equal to the ones of microscopic simulation models, since it considers the same technical characteristics of the rolling stock, motion equations and line and speed profiles.

It must also pointed out that, as it will be discussed in Sections 3 and 4, the timetable planner acceptance requirement implies that our heuristic should not be seen as new, possibly complex, optimization technique, but rather as an engineering tool helpful to practitioners. Its value added is mainly the short time required to obtain a timetable draft. This aspect is of particular interest in the operational studies that must consider several scenarios (for example to define a step-wise improvement plan) and a timetable should be adapted to each scenario. In this context, our heuristic that aims at dramatically reducing the computational burden required to obtain a timetable and to adapt it to a specific scenario that otherwise often becomes a major limitation for these studies. Consequently, our heuristic can be exploited, as an example, to create several timetable drafts to be used as input in the definition of the agreements with Local Authorities or during the capacity assignment negotiations in presence of multiple operators. Our heuristic is also sufficiently flexible that the timetable planner can use it for saturating the grid, for example, with freight trains after having locked the schedules of trains with higher priority.

We applied our heuristic approach to the rail network of the North-East of Italy. It has been tested under different demand conditions, all derived from real-world studies, for example considering an increase of the demand for freight slots or a different structure of regional services. In addition, our heuristic has been used to obtain a rough estimate of the maximum capacity for freight trains, being fixed the passenger services and taking into account the effects of infrastructure improvements.

1.1. Literature review

Since the early 1990s, a rich literature has appeared on the TTP to support timetable planners in meeting the variety of requirements given by operators and customers. The 1998 survey by Cordeau et al. (1998) shows the gradual emergence of combinatorial models for the solution of the railways management problems. Specifically for the TTP, the authors review the earlier papers on periodic timetabling (Caimi et al. 2011; Nachtigall, 1996; Odijk, 1996). All these works are based on the solution of the Periodic Event Scheduling Problem (PESP) introduced for the first time by Serafini and Ukovich (1989). The periodic timetabling is also surveyed in the more recent work by Liebchen and Möhring (2007). The interested reader is referred to this last article for a good introductory to the PESP modeling techniques, and for simple applicative examples. Differently, a good introduction to TTP modeling techniques not based on the PESP is the work by Lusby et al. (2011). This paper presents the most important non-PESP based models, e.g., the ones by (Borndörfer and Schlechte 2008), by Brännlund et al. (1998), by Cacchiani et al. (2008), and by Caprara et al. (2006). All of these articles formulate the TTP in terms of a multi-commodity flow of trains in an appropriate time expanded graph, ruling out conflicts by additional packing constraints (Borndörfer and Schlechte 2008). These models are then solved through Lagragian relaxation and/or column generation techniques. Lusby et al. (2011) underline that these approaches are capable of taking into account more general capacity constraints than the one usually considered in the PESP based literature. However, it also indicates that some further steps are still needed, e.g., toward the integration of the TTP with the platform allocation problem in the stations.

Despite of the wide literature on the problems of timetabling, scheduling and dispatching, only few applications can be found that are implemented in practice or, at least, tested under real-world conditions. As an example, the paper by Törnquist (2006) points out that more than 90% of the approaches in the literature about train scheduling and dispatching have been subject to some experimental tests. However, only less than 5% of them appears to find practical application in the day-to-day operations of railway companies. In this framework, the current literature indicates that instances of sizes relevant for real-world railway applications could not be solved up to now (Cacchiani et al., 2008) using exact algorithms even on the macroscopic models of the railway networks as the ones freely available from the benchmark library TTPlib (Erol et al., 2008). In these macroscopic models, a network consists of stations and tracks. A track is directed and can only be used by one train at each time. Overtaking is only allowed inside stations. Stations are described in terms of platform capacity, running capacity and overall capacity.

Notwithstanding the inherent difficulties in solving TTP, the advantages of a (semi-)automatic generation of timetables have led, e.g., The Netherlands (Kroon et al. 2009), Switzerland (Caimi 2009) and Germany (Liebchen 2008) to use some support systems that solve the PESP problems associated to the TTP. The paper by Kroon et al. (2009) introduces the PESP models and solution techniques used to define the Dutch railway timetables of December 2006 by means of the system DONS (*Designer Of Network Schedules*). This paper explains also how the results obtained for the TTP are then used to define the management policies of the rolling stock and of the crew-scheduling. The kernel module of DONS that solves the TTP implements an algorithm based on constraint programming. This algorithm is partially described by Schrijver and Steenbeek (1994) and by Hooghiemstra et al.(1999) and, according to these authors, it is constantly refined. Differently, Liebchen et al. (2008) indicates that the German railways have chosen a genetic algorithm to solve the PESP problems associated to the timetabling of long distance trains.

There exists a literature that studies the characteristics that practical timetables should enjoy next to the literature on the algorithmic solutions of the TTP. This kind of study is considered, for example, by Johnson et al. (2006), by Wardman et al. (2004) and by Schittenhelm (2010). Specifically, Johnson et al. (2006) and Wardman et al. (2004) discuss the benefits of a periodic timetable, while Schittenhelm (2010) presents the key parameters against which the European railways assess the quality of a timetable and in general of a rail service. The operational costs are discussed by Borndörfer and Schlechte (2008). In particular, the costs of periodic timetables are compared to the costs of trip timetables (i.e., timetables where each trip is independent from the remaining ones). The costs of the periodic timetables are higher on the short horizon, but the difference between costs of the two types of timetables progressively decreases until it disappears when sufficiently long horizons are considered.

The concept of symmetry for periodic timetables is discussed by Liebchen (2004). In a symmetric timetable the travel times on a same route and the dwell times at the same stations are identical in the two directions of a line and the sum of the times of arrival/departure to a single station of two trains in the opposite direction is always equal to 0 modulo period. This article introduces a new kind of constraints for the PESP models to impose the symmetry of the timetables. The authors of this paper comment that, on the one hand, symmetry may induce a significant increase in the total waiting time of passengers. On the other hand, symmetry ensures identical waiting times for any two opposite connections, condition generally appreciated by passengers. For this reason symmetric timetables are used in practice in most countries where regular – interval timetables are deployed, such as Switzerland and Germany. Therefore, it appears important that any timetabling software should allow the users to impose symmetry constraints to be useful for practitioners. Liebchen (2004) also shows that

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