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A new approach to crew scheduling in rapid transit networks

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Abstract

We propose a new approach for the crew scheduling problem in rapid transit networks. With this approach we try to open a new branch for future research, providing a different way of facing the crew scheduling problem which makes integration with other planning problems easier than the traditional approach based on column generation for solving a set covering/partitioning problem. For solving this new model we develop a Lagrangian relaxation and we take advantage of an ad hoc decomposition based on time-personnel clustering. We present some preliminary computational experiments for real case studies drawn from the main Spanish train operator, RENFE.

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Crew scheduling, Lagrangian relaxation, Rapid transit networks.

1. Introduction

Planning processes related to railway systems are fields that are rich in combinatorial optimization problems. Due to the tremendous size of real instances, the planning process is usually divided into several steps such as network design, line planning, timetabling, rolling stock circulations and crew planning (Huisman et al. (2005), Cadarso and Marín (2014)):

1. Network design: designing a Rapid Transit Network (RTN) is a vital strategic subject due to the fact that it reduces the future traffic congestion, travel time and pollution. The location decisions and the maximum coverage of the demand for the new network is the main goal.
2. Line planning: the following step after designing a RTN is planning its lines (origin and destination stations, stops and frequencies). The problem of designing a line system aims at satisfying the travel demand while maximizing the service towards the passengers or minimizing the operating costs of the railway system.

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3. Timetabling: the general aim of the railway timetabling problem is to construct a train schedule that matches the frequencies determined in the line planning problem.
4. Rolling stock circulations: they are determined in order to satisfy both the timetable and the demand. The train unit type and composition assignment to each train service and a sequence for each train unit in the network are determined.
5. Crew planning: it consists in assigning different tasks (e.g., train services) that must be done to available workers (the crewmembers). While the idea is simple, the problem can get very complex due to different matters (e.g., strong labor rules). This and the complexity of real world instances make the crew planning problem a challenge, so it is usually split into two different phases: the crew scheduling and the crew rostering problems. The former one focuses on a short planning period while the latter one focuses on long planning periods.

In the last few decades, the Crew Scheduling Problem (CSP) has been studied widely. The increase in research attention could be motivated by economic considerations. For many companies, labor cost is the major direct cost component. Cutting this cost by only a few percent by implementing a new crew schedule could therefore be very beneficial (Van den Bergh et al. (2013)).

The work presented here is also focused on the CSP, which consists in assigning tasks to generic crews in a short temporal horizon. Tasks are usually grouped into duties. We assume that the CSP is tackled just after rolling stock circulations have been determined.

Almost all the research made before related to the CSP follows the same philosophy: the problem is divided into two different problems, making use of the column generation approach (Barnhart et al. (1998)). One of the problems consists in a set partitioning (or set covering, depending on how deadheads are considered) where a subset of duties covering all the tasks at a minimum cost is determined. The other one, the duty generation problem, consists in generating feasible candidate duties (columns). Duties are usually generated using constrained shortest path algorithms and taking into account dual prices of the master problem. The solution finding process is therefore iterative, alternating between both problems until the optimal (or a good enough solution) is found.

The classical point of view, which has been extensively applied to airlines and railways (Barnhart et al. (2003),Kroon and Fischetti (2001)), offers good advantages such as being able to deal with non-linear payment systems or very complex labor rules. However, in this paper we present a new approach to deal with the CSP in RTNs; such networks operate in metropolitan areas, and feature frequent train services and heavy passenger loads. The new approach presented here offers the following advantages, which exploit the particularities of RTNs such as their linear payment systems. First, the integration of the CSP with other planning problems becomes easier, since it is based on sequencing. Second, its application to recovery problems may exploit the fact that previously computed duties which are affected by a disruption are not forced to be discarded totally, but only partially. And finally, it opens a new branch for future research, providing a different way of facing the CSP.

This paper is organized as follows. In Section 2 a literature overview and paper contributions are given. Section 3 describes the problem in detail. Section 4 is devoted to the mathematical model. In Section 5 we present our solution approach. In Section 6 we show the computational experiments we have performed. Finally, we draw some conclusions in Section 7.

2. Literature review

The CSP has been widely studied in the literature. Van den Bergh et al. (2013) presents a survey for the personnel scheduling, which covers, among others, the CSP applied to different transport modes.

Concerning the airline industry, a industry where a great research effort has been done in the CSP, Barnhart et al. (2003) describe the crew planning problem, referred as crew scheduling, which is divided into crew pairing and crew rostering problems (nomenclature in the literature is different depending on the transport mode under study). They model both problems as set partitioning or set covering problems, which represent the most common formulations. Bomdörfer (1998) investigates polyhedral, algorithmic and application aspects of such models.

For railway applications, Huisman et al. (2005) present a survey of the general planning process. Kumar et al. (2009) describe the railroad crew scheduling problem defining terminology and labor rules. They tackle the problem as an integer programming model and present several solution methods. Caprara et al. (1997) give an outline of