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Passenger centric train timetabling problem

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ABSTRACT

The aim of this paper is to analyze and to improve the current planning process of the passenger railway service in light of the recent railway market changes. In order to do so, we introduce the Passenger Centric Train Timetabling Problem. The originality of our approach is that we account for the passenger satisfaction in the design of the timetable. We consider both types of timetable(s): cyclic and non-cyclic. The problem is modeled as a Mixed Integer Linear Programming (MILP) problem with an objective of maximizing the train operating company's profit while maintaining ε level of passenger satisfaction. The model does not take into account conflicts between trains and does not adjust dwell times at stopping stations among the lines. By solving the model for various values of ε, the approximated Pareto frontier is constructed. The analysis, based on an experiment using realistic data, shows that an improvement of passenger satisfaction while maintaining a low profit loss for the railway company can be achieved. A sensitivity analysis on passenger congestion illustrates a quantitative evidence that the non-cyclic timetables can account better for high density demand in comparison to cyclic timetables.

1. Introduction

The main product of a Train Operating Company (TOC) is a train timetable, with its consumers being the passengers. It is then important to account for the passengers' preferences during the timetable design, especially with the new legal modifications in the railway markets in Europe (EU Directive 91/440) that allow for competition.

Up to this point, the European national carriers were subsidized by local governments and their purpose was to offer the accessibility and mobility to the public (passengers). With this new market settings, the subsidies are removed and the operators compete not only for the passengers, but also for the infrastructure. The railway network is to be separated from the TOC who has built it (usually the national carrier) and to be handled by an independent Infrastructure Manager (IM). Each TOC will then be obliged to submit its preferred timetable to the IM, who will then adjust the proposed timetables, in order to secure the safety of the network. No common decision rule, on which TOC should gain advantage in case of a conflict, yet exists, but an economic instrument such as bid-auction is expected. Adding everything up, the above facets of the problem put a high pressure on the timetable design and ask for a quantitative method that would provide TOC with

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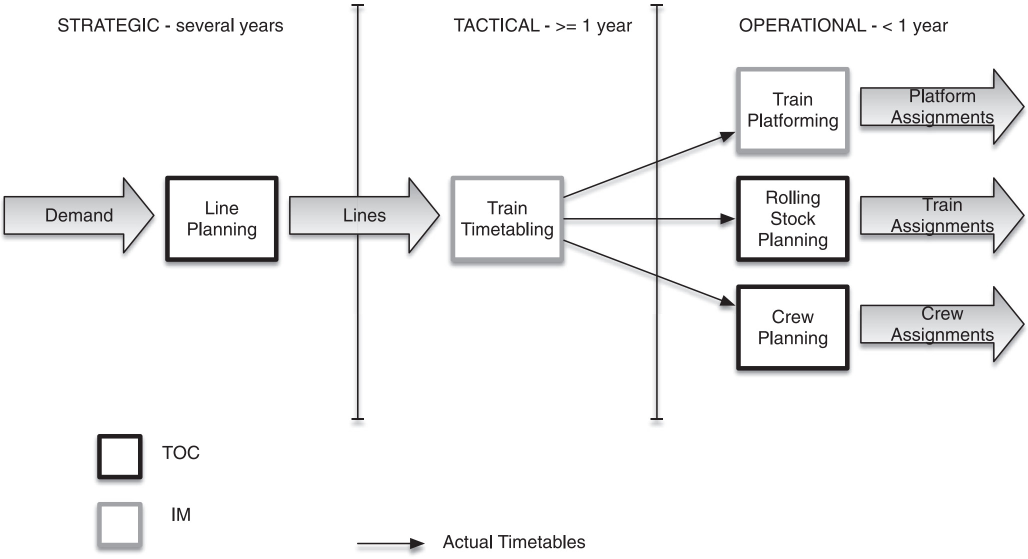

Fig. 1. Planning overview of railway operation.

an insight about a precise yet functional timetable design that could take into account operational constraints as well as passengers' satisfaction.

The new planning horizon as described in Caprara et al. (2007) is visualized in Fig. 1. In the previous market settings, all the stages were solved by one TOC, whereas now the interaction between several TOCs and IM is required. The timetable design itself consists of two well-known sequential problems: the Line Planning Problem (LPP) and the Train Timetabling Problem (TTP). In the first stage, each TOC solves the LPP based on a pre-processed pool of potential lines and the estimated aggregated demand between every Origin Destination (OD) pair. The LPP selects the most suitable combination of the lines and their frequencies with an objective of maximizing the number of direct travellers and/or minimizing the operating cost. For more information on the LPP, refer to the latest survey by Schöbel (2012).

In the next stage, the IM collects the timetable requests of each TOC and resolves potential conflicts by solving the TTP. As discussed above no universal objective function is defined. Two versions of the TTP exist: non-cyclic and cyclic. In the non-cyclic model, the IM receives ideal timetables as an input. They are defined as the most profitable schedules. The objective of the problem is to maximize the profit of the adjusted conflict-free timetables Caprara et al. (2002). The problem does not take into account connections between the trains and thus the timetable adjustments might disconnect the trains and cause discomfort to the passengers. In the cyclic model the focus is on the cyclicity (*i.e.* feasibility) of the proposed timetable rather than on optimizing profit Caprara et al. (2007). Although some user-defined objective functions exist Peeters (2003). In the cyclic TTP, the connections between the trains are always secured. However, it is not known if these connections are actually used by the passengers. By the definition of cyclicity, *i.e.* repeating pattern that is easy to remember, the approach is considered passenger oriented. Note that the TTP models in the current literature often deal with the old market settings even though the non-cyclic TTP could be suitable for the IM (as described in Caprara et al. (2007). All the problems in the above planning horizon are offline, *i.e.* they are solved before the planned operation.

We identify here a gap between the LPP, that focuses on passengers (minimize travel time) and operator (minimize cost), and the timetable problem, that focusses on profit or cyclicity. The inconsistency between the several objectives may be counter productive (as we show later in this paper). The operator's goal is to maximize his profits and the passengers' goal is to receive the best possible service from their origin(s) to their destination(s). The two goals are in competition: the best possible service for passengers may also be the most costly alternative for the operator. Therefore, we propose to address the problem of designing the timetable, taking into account both satisfaction of the passengers and the profit of the operator.

The operator's profit as such is usually well defined. The passenger satisfaction needs specific modelling, based on utility theory. The (dis)utility of traveling for an individual is a function of various features of the trip: the time spent in the train, the time spent waiting, the number of transfers from one train to another and the timeliness at the destination.

In the published literature, passenger satisfaction based on the first three elements already exists and is assessed together using the results of discrete choice models (*i.e.* the passenger perception): the waiting time has a larger relative weight than the in-vehicle-time, the transfer from one train to another is penalized by adding extra in-vehicle-time Kanai et al. (2011), Sato et al. (2013). The presented application (Kanai and Sato) is from the delay management, where the passengers are already in the network and the goal is to minimize dissatisfaction. In the offline version of train timetabling, the time of