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Discrete Optimization

On solving multi-type railway line planning problems

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Abstract

An important strategic element in the planning process of a railway operator is the development of a line plan, i.e., a set of routes (paths) on the network of tracks, operated at a given hourly frequency. The models described in the literature have thus far considered only lines that halt at all stations along their route. In this paper we introduce several models for solving line planning problems in which lines can have different halting patterns. Correctness and equivalence proofs for these models are given, as well as an evaluation using several real-life instances.

Keywords: Integer programming; Combinatorial optimisation; Railway transportation

1. Introduction

The planning problem faced by every railway operator consists of several consecutive stages, ranging from strategic decisions concerning, e.g., the acquisition of rolling stock, to operational traffic control. Strategic problems are largely driven by estimates for the long-term demand. Together with infrastructure data, such as the railway tracks and stations, these demand data are input for the strategic line planning problem considered in this paper. It involves the selection of paths in the railway network on which train connections are operated. Thus, the line planning problem focuses on determining a subset of all possible paths (lines) that together make up the line plan, such that the provided transportation capacity is sufficient to meet the passenger demand. Relevant objectives are the provided service towards the passengers and the operational costs for the railway operator.

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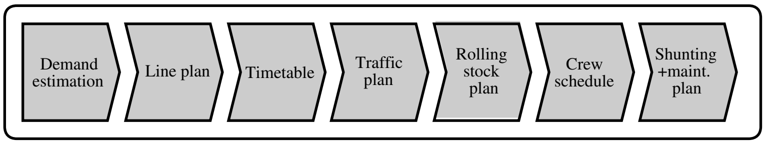

Fig. 1. The different stages in the planning process.

Successive decision stages, as shown in Fig. 1, are the more detailed planning problems such as the construction of timetables [9,10,14], traffic planning (route assignment, platform assignment) [16], rolling stock planning [1,12,13], crew scheduling [3,8] and shunting planning [5,6,15].

Besides the operated paths, a line plan also specifies the hourly frequencies of the lines and their halting patterns. The halting pattern defines the stations along a line's route at which it halts. Halting patterns for train lines can be divided into classes, called *types*, such as Regional, Interregional and Intercity. The line planning models described in the literature have thus far considered all lines to be of the same type (see [2,4,7]). Solving problems with more than one type was done by a priori assigning the passengers to the different train types, thus splitting the original problem into separate problems for every type. This allocation was determined, for example, by the procedure System Split (see [11]). In this paper, we introduce several generalisations of the previous models to simultaneously solve cost-optimising line planning problems with multiple train types.

Traditionally, the objective when constructing a line plan has been to find a set of lines that maximises the number of direct travellers, as in Bussieck [2]. This is an obvious objective from a service perspective, since it maximises the number of travellers that do not have to change trains during their journey. However, this objective tends to generate geographically long train lines, since the longer the lines, the more direct connections are provided. Such long lines often have large fluctuations in the number of passengers on different parts of their route. Therefore, long train lines can result in unused capacity on the less busy tracks, and can thus be inefficient and expensive. As an alternative objective, similar to Claessens et al. [4], Bussieck [2] and Goossens et al. [7], this paper focuses on models for minimising the operational costs of a line plan.

The next section recalls the single-type line planning problem, and introduces new definitions for the multi-type model. In Section 3 we discuss how to formulate the multi-type model by using an intermediate problem, called the edge capacity problem. For this problem we consider a number of model formulations in Section 4. Apart from a multi-commodity flow formulation, we develop two alternative mathematical formulations and prove their equivalence. In Section 5 we describe a computational study, based on instances of the Dutch railway operator NS Reizigers.

2. Modelling

The concept of a line is fundamental in a railway system for passenger transportation. A line specifies a route between an origin and a destination station and the subsequent stops, combined with an operated hourly frequency. The line plan is the set of operated lines. The line plan does not incorporate the exact timetable for the operated lines, though we assume that the timetable will be cyclic with a cycle time of one hour, i.e., that the line plan is repeated every hour. Note that this still allows for lines to be operated with a frequency of for example 2, i.e., twice per hour. The models described here focus on finding a line plan that minimises the induced operational costs (see [2,4,7]).

Before discussing models for simultaneously solving multi-type line planning problems (MLPP), let us first recall the single-type cost-optimising line planning problem (LPP).