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Timetable coordination of first trains in urban railway network: A case study of Beijing

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ABSTRACT

A model of timetable coordination of first trains in urban railway networks, based on the importance of lines and transfer stations, is proposed in this paper. A sub-network connection method is developed, and a mathematical programming solver is utilized to solve the suggested model. A simple test network and a real network of Beijing urban railway network are modeled to verify the effectiveness of our suggested model. Results demonstrate that the proposed model is effective in improving the transfer performance in that they reduce the connection time significantly.

1. Introduction

There is an increasing development worldwide for urban railway network (URN) as an effective transportation mode to alleviate traffic congestion in cities. The denser an URN is, the more convenient it becomes to the travelers. However, having more lines and stations to an URN increases the complexity of timetable optimization for the system. What's more, the earlier the departure times for first trains, the higher operation cost to the URN. There are therefore trade-offs to be made between travelers who want short transfer waiting time and operators who want to minimize operational costs. Trade-offs are also to be made between different departure times for different lines, such that the overall transfer connection times are small. This is considered as the first train timetabling coordination problem.

Generally, timetable optimization is to design a schedule which can help transportation authorities to maximize their service level (such as minimizing transfer time, maximizing transfer accessibility), or to minimize some generalized cost of a combination of the above. There are many studies focusing on the transfer time, and optimization models are proposed to design or adjust a timetable. For example, Jansen et al. [1] applied Tabu search method to adjust the dispatching times of trains on a route to synchronize the timetable by minimizing passenger transfer time. Cevallos and Zhao [2] aimed to change an existing timetable by considering the coordination between lines. In their paper, the objective was to reduce the waiting time at the transfer stations. Chen and Wang [3] proposed a method for calculating a reasonable departure time by decreasing the waiting time at transfer stations during the day. Wong et al. [4] presented a mixed-integer-programming optimization model for schedule synchronization problem which minimizes the transfer waiting times of all passengers. They applied the method to the Mass Transit Railway of Hong Kong. Shafahi and Khani [5] proposed two mixed integer

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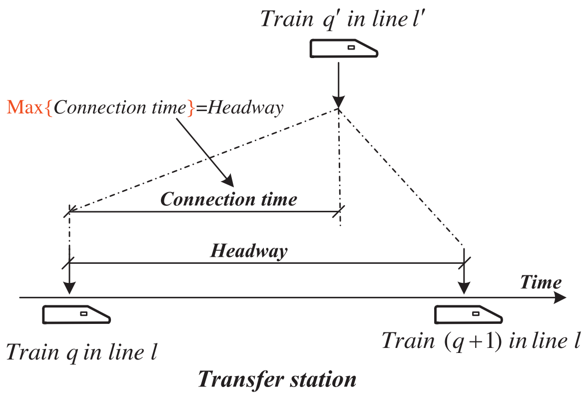

Fig. 1. The connecting trains in normal operation trains.

programming models to minimize the total waiting time at transfer stations. Yang et al. [6] considered the optimization of energy consumption and travel time as the objective based on a coasting control method. Wu et al. [24] proposed a timetable synchronization optimization model to optimize passengers' waiting time while limiting the waiting time equitably over all transfer stations in Beijing URN. Nayeem et al. [7] proposed two algorithms on minimizing the waiting time and the number of transfers simultaneously.

Other researchers have concentrated on the aspect of the generalized cost to design the optimized timetable. Yan and Chen [8] developed a model for intercity timetable setting. The model is formulated as a mixed integer multiple commodity network flow problem. Zhao and Zeng [9] proposed a model to minimize passengers' transfer cost and presented a heuristic method to optimize transit network planning. In the study, the transfer cost is separated into walking time between stops, the waiting time at transfer stations and transfer penalty time. Meanwhile, simultaneous approach of optimal passenger cost and timetabling of transit systems has only been superficially explored, the synchronization between schedules and operational status is still to be resolved. Gallo et al. [10] examined the frequency optimization problem under the assumption of elastic demand in a regional metro system. The objective of the model is to minimize the generalized cost which combines of transit user costs, car user costs, operator costs and external costs. Yang et al. [33] proposed a fully comprehensive survey on energy-efficient train operation to reduce operation cost. Sun et al. [11] formulated three optimization models to design a capacitated demand-sensitive peak and off-peak timetables.

There have been studies in dynamical re-scheduling in response to real-time information to enhance the service quality of URN. Taniguchi and Shimamoto [12] presented a dynamic vehicle scheduling model that incorporates real-time information using variable travel time. Dynamic traffic simulation was utilized to update travel time. Vansteenwegen and Oudheusden [13] proposed a linear programming model considering delay time in the actual operation. They aimed to compute the ideal buffer times for each connection, which was subsequently used in the linear program model for re-scheduling. Yan et al. [14] developed a scheduling model which considers stochastic demand. They applied a simulation technique, coupled with link-based and path-based routing strategies, to develop two heuristic algorithms to solve the problem. Niu and Zhou [15] developed integer programming models to optimize train timetables in a heavily congested urban rail corridor. Based on time-dependent, origin-to-destination trip records from an automatic fare collection system, a nonlinear optimization model was designed to solve the problem on a realistic sized corridor.

In timetabling problem, several inputs are necessary, e.g., service time of day, departure time for the first train, departure time for the last train and schedule for during-the-day operation. Most of the existing literature studies on the subject of timetabling for URN have been concerned with the 'normal' operation during the day, when the service can be considered infinite and there is not a start or an end of the service. Scheduling for during-the-day operation is different to that for the first or the last trains. For during-the-day operation, the high service frequencies naturally reduce the connection time at transfer stations. All trains can connect to the feeder trains or be connected by other trains and within a reasonably short period of time. For example, at transfer station (Fig. 1), for passengers from the q' train in line l' transferring to connecting q train in line l, their maximum connection time tends to be the headway of line l. During the peak period, when transit frequencies are high, Chakroborty [23] demonstrated that missing a connection only increases transfer connection time by a relatively short interval. On the other hand, during off-peak period, Yan and Chen [8] argued that when transit frequencies are low, missing a connection means long waiting times and the absence of synchronization may even discourage people from using public transport. In other words, it is important to study the synchronous timetable in off-peak hour.

The first train timetabling problem which occurs in the morning off-peak hour becomes ever more important with the expansion of URN. The first train indicates the first operating train in each line every day. Passengers usually have to transfer to the other line(s) to complete their travel within the network. Therefore they are more concerned with service connectivity and transfer coordination. Trade-offs need to be made between passengers' perspective and operator's perspective to set the departure times for first trains within reasonable cost, without causing excessive long connection time at any transfer station in the URN. To illustrate the problem, we assume that the first train in line l' has to connect to the first train in line l in