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Multiperiod-based timetable optimization for metro transit networks

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ABSTRACT

This paper tackles the train timetable optimization problem for metro transit networks (MTN) in order to enhance the performance of transfer synchronization between different rail lines. Train timetables of connecting lines are adjusted in such a way that train arrivals at transfer stations can be well synchronized. This study particularly focuses on the timetable optimization problem in the transitional period (from peak to off-peak hours or vice versa) during which train headway changes and passenger travel demand varies significantly. A mixed integer nonlinear programming model is proposed to generate an optimal train timetable and maximize the transfer synchronization events. Secondly, an efficient hybrid optimization algorithm based on the Particle Swarm Optimization and Simulated Annealing (PSO-SA) is designed to obtain near-optimal solutions in an efficient way. Meanwhile, in order to demonstrate the effectiveness of the proposed method, the results of numerical example solved by PSO-SA are compared with a branch-and-bound method and other heuristic algorithms. Finally, a real-world case study based on the Beijing metro network and travel demand is conducted to validate the proposed timetabling model. Computational results demonstrate the effectiveness of adjusting train timetables and the applicability of the developed approach to real-world metro networks.

1. Introduction

As the most reliable and energy efficient transportation system, metro transit has been developed as a solution to mitigate road congestion and associated environmental pollutions, and thus plays an increasingly important role in many large cities over the world (Kang et al., 2015a). Due to the large scale of the network, the design of metro transit is often addressed into two stages, tactical planning and operational management. Various decision-making problems arise accordingly, such as line planning, timetable generation, vehicle scheduling, and crew scheduling (Ceder, 2007; Ibarra-Rojas and Rios-Solis, 2012; Yang et al., 2013; Yang et al., 2016). As one critical challenge in the planning stage, timetable design affects, to a significant extent, the service quality as well as those subsequent planning problems including path and crew scheduling.

Transfer synchronization of different train lines affects the service quality to a large extent. In addition to travel time on trains, the maximal transfer synchronization time of different trains will be just close to headway in the peak period,

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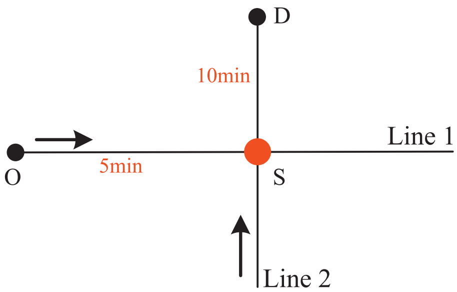

Fig. 1. Illustration of a small network.

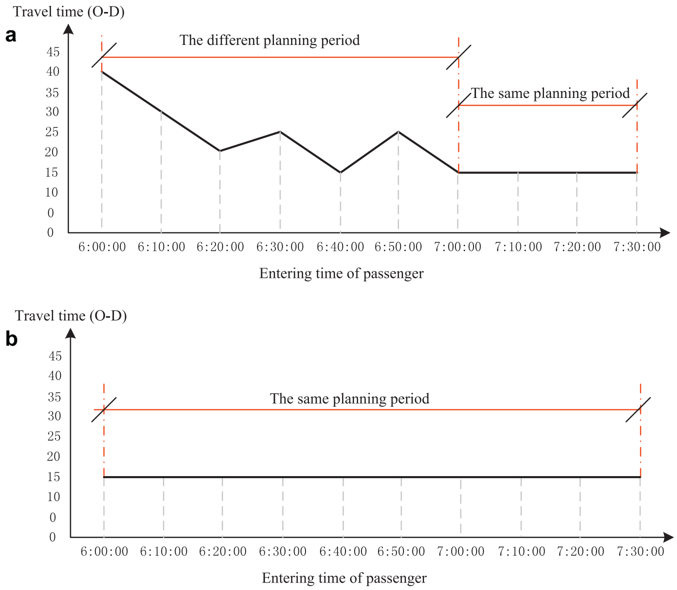

Fig. 2. (a) A snapshot of small metro network. (b) A snapshot of small metro network.

Table 1
The headways in different time periods.

Line 1	Departure time of first train		06:00:00	
	Time period	06:00:00–07:00:00		07:00:00–07:30:00
	Headway (min)	20		10
Line 2	Departure time of first train		06:30:00	
	Time period	06:30:00–07:00:00		07:00:00–08:00:00
	Headway (min)	15		5

Note: The time is represented in the 24-h HH:MM:SS format.

because frequencies tend to be high and missing a connection only increases passengers' transfer waiting time by a relatively short interval (Chakroborty, 2003). In contrast, for those who make transfers through different lines during the off-peak period, when service frequency is low, passengers may spend additional time waiting for train services. Moreover, considering the varied travel demand of an entire day, rail operators commonly adjust timetables and change headways from period to period, e.g., the first train period, the morning peak period, the morning off-peak period, the afternoon peak period, the afternoon off-peak period and the last train period. For a metro transit network (MTN) which is operated by multiple rail operators, different operating strategies may be adopted for different lines. Inappropriate synchronization of train services in different lines during the transitional period (from peak to off-peak hours or vice versa) may lead to an unacceptable amount of waiting time for passengers. Therefore, it is necessary to enhance the transfer synchronization between different rail lines.

We use a small network to illustrate this problem (see Figs. 1 and 2). In Fig. 1, there is an OD (origin to destination) pair and a transfer station *S*. Running directions are denoted by arrows and the running time is marked in red. The initial departure time and headways in various periods are provided in Table 1. Assume that the walking time and boarding time equal to zero.