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A simulated annealing algorithm for first train transfer problem in urban railway networks

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ABSTRACT

Passengers often have to transfer between different subway lines to reach their destinations. Time coordination of first trains between feeder and connecting lines plays an important role in reducing passenger transfer waiting time. This paper addresses the first train synchronization problem, and proposes a first train coordination model which aims at minimizing total passenger transfer waiting time. Taking into account the specification of the first train problem, we use mixed-integer variables to enable the correct calculation of the waiting time for the "first available" train at each transfer station. In addition, we develop a simulated annealing algorithm to deal with a case study of the Beijing subway network. Results indicate that the proposed approach reduces the passenger waiting time from 705.1 min of the original first train timetable to 567.42 min of the scheduled one.

1. Introduction

The development of public transportation is an increasingly popular topic in metropolises. Facing road congestion, car parking and air pollution problems, travelers are more likely to select public railway transit if they are provided with good services at their disposal, e.g., comfort, punctuality, security, regularity, and economy. It is the goal of operators to design such an urban railway transit to ensure the quality of the transportation service. The train timetabling problem (TTP) in urban railway networks is to find an effective train schedule that regulates train arrival and departure times at stations. Introduced by Lusby et al. [1], TTP is one of the most time consuming, important and difficult tasks in passenger railway planning and management. Moreover, we can see in Fig. 1 that the timetabling is the basis of track allocation, train routing (in stations), rolling stock scheduling and crew scheduling problems. To develop a timetable, several inputs are necessary (see Table 1), e.g., demand by time of day, time for first and last trips and running times. As a result, the outputs of the whole timetable are trip arrival and departure times.

Fig. 2 illustrates the topology of a simple subway network. Trains are dispatched at a regular headway of each line, from the original station to the final station. Trains stop at intermediate stations as well as transfer stations to let passengers get on, get off and exchange. However, the first train transfer problem is usually critical if it is not paid much attention to. Herein, the first train indicates the first operating train in each line every day. Taking the Beijing subway in Fig. 2 for instance, four first trains depart from vehicle depots in two bi-directional lines (Line 1 and Line 10). The first train running in the **down** train direction of **Line 1** (L1D) arrives at GuoMao station at 5:05 am, and the first train in the **down** train direction of

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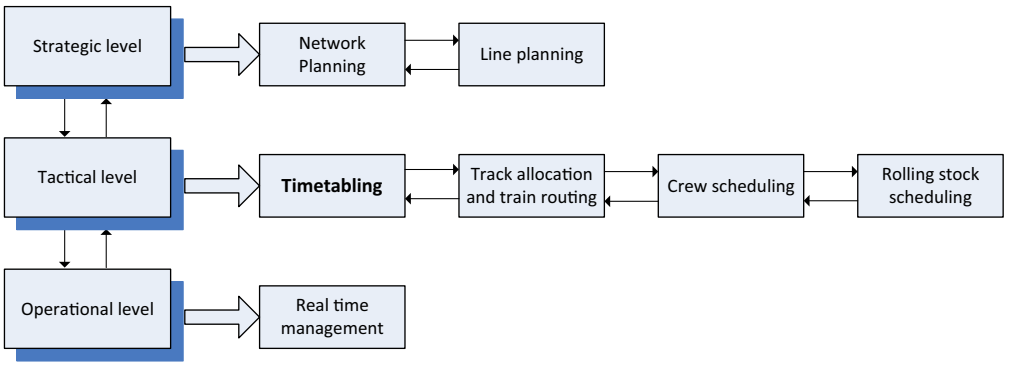

Fig. 1. Hierarchy of decision problems in the railway planning and management [1].

Table 1
Transit planning process [9].

Necessary inputs	Planning activity	Outputs
Demand by time of day Times for first and last trips Running times	Timetable development	Trip departure times Trip arrival times

Station	First feeder train		Transfer	First connecting train	Waiting
GuoMao	L1D→L10D	5:05:00	4.5 min	5:48:00	38 min 30 sec
	L1D→L10U	5:05:00	4.5 min	6:13:00	63 min 30 sec
GongZhuFen	L1U→L10D	5:17:00	3 min	6:30:00	70 min
	L1D→L10D	5:36:00	3 min	6:30:00	51 min

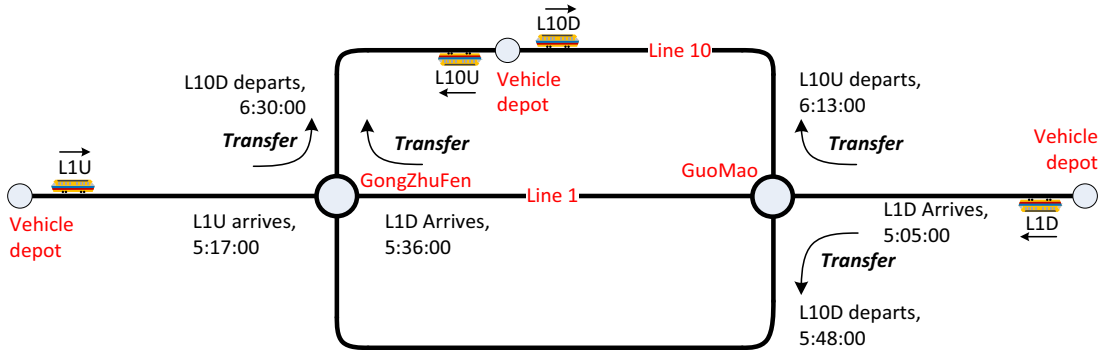

Fig. 2. A snapshot of the first train timetable in Beijing subway.

Line 10 (L10D) departs at 5:48 am. It takes passengers 4.5 min to transfer between line 1 and line 10. As a result, the transfer waiting time from L1D to L10D is approximately 38.5 min that makes passengers wait too long. In addition, the transfer waiting times for passengers from L1D to L10U at GuoMao, from L1U to L10D at GongZhuFen, and from L1D to L10D at GongZhuFen reach 63.5 min, 70 min and 51 min, respectively. It is no exaggeration to say that long waiting time discourages passengers from riding urban railway transit.

Fig. 3 shows two different situations base on the arrival/departure times of the first feeder train and the first connecting train; the arrows above the timeline represent arrival times of trains at one transfer station on line l, while the arrows below capture departure times of trains at the transfer station on line l'. Case A is under the scheduled first train timetable and case B is not, which means the first train transfer time of A is less than that of B. Both A and B adopt a fixed headway timetable. As seen in case A and case B, passengers transfer from train 1 to train 1′, from train 1′ to train 2, from train 2 to train 2′, etc. For the first two groups of transfers, we have the following equation,

$$(transfer + wait^{1}_{1'}) + (-dwell_{1'} + transfer + wait^{1'}_{2} - dwell_{2}) = Headway_{l}, \tag{1}$$