Transportation Research Part B 104 (2017) 568–582

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Two-phase decomposition method for the last train departure time choice in subway networks

Liujiang Kang, Qiang Meng*

Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576, Singapore

ARTICLE INFO

Article history:
Received 23 October 2016
Revised 29 April 2017
Accepted 1 May 2017
Available online 8 May 2017

Keywords:
Urban subway networks
Last train departure time choice
Mixed-integer linear programming
Global optimization method
Two-phase decomposition method

ABSTRACT

An urban subway network with a number of service lines forms the backbone of the public transport system for a large city of high population, such as Singapore, Hong Kong and Beijing. Passengers in these large cities heavily rely on urban subway networks for their daily life. The departure times of the last trains running on different lines of an urban subway network should be well coordinated in order to serve more passengers who can successfully transfer from one line to another, which is referred to as the last train departure time choice problem. This study aims to develop a global optimization method that can solve the last train departure time choice problem for large-scale urban subway networks. To do so, it first formulates a mixed-integer linear programming (MILP) model by introducing auxiliary binary and integer decision variables. For the real-life and large-scale instances, however, the formulated MILP model cannot be solved directly by the global optimization methods such as branch-and-bound algorithm invoked by CPLEX – one of the powerful optimization solvers because of the instance sizes. An effective two-phase decomposition method is thus proposed to globally solve the large-scale problems by decomposing the original MILP into two MILP models with small sizes. Finally, a real case study from the Beijing subway network is conducted to assess the efficiency and applicability of the two-phase decomposition method and perform the necessary sensitivity analysis of the operational parameters involved in the last train departure time choice problem.

1. Introduction

An urban subway network comprising a number of service lines forms the backbone of the public transport system for a large city including Singapore, Hong Kong and Beijing. The great importance of the urban subway networks for the daily life of people in these large cities with high populations can be demonstrated by the ridership distribution of different transport modes. For example, the modal share of subway transport in Beijing occupied 16.5% in 2013 and it would sharply burst to 34.7% in 2020 according to the blueprint of the Beijing Government. In Singapore, the average daily ridership of urban subway reached 2.3 million in 2013, accounting for 18.4% of the modal share across all transport modes. As for Hong Kong, its MTR (mass transit railway) had an average ridership of 4.18 million with a modal share exceeding 36% in 2013.

A station in a subway network is referred to as a transfer station if more than one line crosses at the station. The spatial distribution of the transfer stations determines the topological connectivity of a subway network. As an urban subway network is not operated in 24 h every day, the last train connection issue at transfer stations, where some passengers change

* Corresponding author.
E-mail address: ceemq@nus.edu.sg (Q. Meng).

http://dx.doi.org/10.1016/j.trb.2017.05.001
0191-2615/

from one line to another, arises practically. To solve this issue, the arrival times of the last trains at transfer stations should be coordinated well. Otherwise, some midnight passengers would miss the last train services (i.e., last-train transfer failures), and thus they have to take an expensive taxi or a long-transit-time midnight bus to get their homes. The arrival times of the last trains at transfer stations are largely determined by their departure times from the terminals since the segment running times and station dwell times are generally fixed by operating companies. Hence, we propose a practical last train departure time choice problem which aims to find an optimal departure time solution of the last trains serving different lines of an urban subway network so that more passengers can catch the last trains successfully with shorter transfer connection times. Moreover, with an ideal last train timetable, passengers can check the provided online map to ensure smooth connections. In short, this paper addresses the last train transfer problem by optimally determining the departure times of the last trains from terminals in a subway network with practical train operational constraints so as to maximize the last train transfer connections and to minimize the last train transfer connection times.

1.1. Related studies

The proposed last train departure time choice problem for the urban subway networks is distinct from the conventional train timetabling problems that aim to determine a periodic/non-periodic timetable for a set of trains subject to the track and station capacity constraints as well as some necessary operational constraints. Young (1970) is the first study to investigate the train timetabling problem for the subway networks. After this seminal work, several variations with different objective functions and underlying railway network structures have been addressed in the literature, including Cordeau et al. (1998), Zhou and Zhong (2005, 2007), Caprara et al. (2002), Cacchiani et al. (2014), and so forth. From the perspective of train service operators, when optimizing the train timetables, it is common to take the benefit of the train service operators into account. For example, examine the trade-off between the level of service and operating cost (Ibarra-Rojas et al., 2014), minimize the train running time (Chevrier et al., 2013), and maximize the profit earned by the train service operators (Lin and Ku, 2014). From the perspective of passengers, it is more important to improve the level of train services by optimizing train timetables. A widely adopted objective is to minimize the waiting times of passengers at stations. For example, Niu and Zhou (2013) found that under the passenger arrival pattern at stations following uniform distributions, a schedule with a constant headway between two consecutive trains could reduce the waiting time of passengers. Niu et al. (2015) further considered the time-dependent travel demand and the skip-stop strategy of a train service by developing a unified quadratic integer programming model, which was solved via the GAMS program.

There is no doubt that both passengers and operators prefer a robust train timetable that can mitigate the delay propagation as much as possible in case of disruptions in the train services. Cacchiani and Toth (2012) made a nice literature review on the robust train timetabling studies. Fischetti et al. (2009) proposed the robust optimization based techniques to improve the robustness of a given train timetabling solution. It should be pointed out that the applications of the robust timetables in the train services are described and evaluated by Liebchen (2008). Cacchiani et al. (2012) modified an existing Lagrangian heuristic method to produce the robust solutions for train timetabling, showing that the performance of a simple modification of a given Lagrangian heuristic was able to cope with robustness.

The subway systems offer the reliable services with sufficient punctuality in practice (Krasemann, 2012). However, the unexpected emergencies (e.g., signal problems and outburst mass passenger flow) are also common in the train daily operations and management. With the development of the Automatic Train Control (ATC) system, the real-time train timetable rescheduling using the operations research techniques is currently an active research area. Pellegrini et al. (2014) proposed a mixed-integer linear programming (MILP) model for the train routing and scheduling in case of disruptions. Kang et al. (2015b) minimized the difference between the original timetable and the rescheduled one when dealing with the last train delay issues. Yin et al. (2016) proposed a stochastic programming model for the metro train rescheduling problem. Cacchiani et al. (2016) proposed an integer linear programming model for the train rescheduling, in which they aimed at designing the conflict free schedules that differ as little as possible from the ideal ones. Lamorgese et al. (2016) built an MILP model to minimize the deviations from the official timetable, and solved it with a Benders' -like decomposition method within a suitable master scheme.

The first and last train transfer issues have not received much attention by researchers while both the train service operators and regulators (e.g., Beijing and Shanghai) are concerned with these issues. For the first train timetabling, transfers in a large-scale and complex subway network often face the long waiting time that have to be addressed (Kang et al., 2016). As for the last train transfer problem, building connections is the primary concern. Kang et al. (2015a) studied the last train transfer problem with the focus on the subway network connection by developing a nonlinear programming (NLP) model to reveal the relationship between transfer connection time and transfer waiting time for the last train services. Kang and Zhu (2017) developed the NLP models to strategically optimize the last train timetables to balance the last train connections cross the service lines operated by different operators. Guo et al. (2016) and Kang and Zhu (2016) examined the first train timetabling problem with the objective of improving the transfer performance by reducing waiting times. It should be pointed out that the mathematical programming models proposed for the first and last train issues are solved by the heuristic methods including the genetic algorithm instead of the global optimization methods. Dou et al. (2015) proposed an optimal bus schedule coordination problem in an intermodal bus-and-train transport network by offsetting and perturbing the original bus schedules to reduce transfer failures from bus service to the last train service for the given last train schedule.