Transportation Research Part C 61 (2015) 63–74

Contents lists available at ScienceDirect

Transportation Research Part C

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

Robust stop-skipping patterns in urban railway operations under traffic alteration situation

A. Jamili [a,*], M. Pourseyed Aghaee [b]

[a] School of Industrial Eng., College of Engineering, University of Tehran, Iran
[b] Railway Department, Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form 25 September 2015
Accepted 25 September 2015
Available online 6 November 2015

Keywords:
Stop-skipping approach
Train timetable patterns
Robust mathematical model
Decomposition-based heuristic algorithm
Simulated annealing algorithm

ABSTRACT

In this paper an operation mode which is based on the stop-skipping approach is studied in urban railway lines under uncertainty. In this mode, each train follows a specific stop schedule. Trains are allowed to skip any intermediate stations to increase the commercial speed and to save energy consumption. As the commercial speed increases, the number of required trains in operation reduces and results eliminating unnecessary costs. To that end, a new mathematical model is proposed to reach the optimum stop schedule patterns. In the planning step, based on the traffic studies, the headway distributions are computed for different weekdays, and holidays. However, in practice, because of many unexpected events, the traffic may alter from what is planned. Therefore, in this condition, a robust plan is required that is optimized and immunized from uncertainty. In this paper, a new robust mathematical model, as well as two heuristic algorithms including (1) a decomposition-based algorithm and (2) a Simulated Annealing (SA) based algorithm is proposed. Finally, an Iranian metro line is studied and the optimum patterns are presented and analyzed.

1. Introduction

Urban railway systems are generally operated in two different classes: short loops and long loops. These modes of operations are defined based on the traffic analysis. Generally, short loop operation requires more facilities and more complicated operation, but requires less number of trains, and results in a significant reduction in repair and maintenance costs. In addition to this approach, stop-skipping approach is another method which increases the commercial speed, and reduces the number of unwilling stops. Both short-loop operation and stop-skipping approach result in reducing the number of required trains.

The most important input data in operation plan studies is the number of passengers boarded and alighted, already determined by traffic studies. In the planning step, based on these input data, the headway distributions are computed for different weekdays, and holidays. In practice, as many unexpected events may occur, the estimated traffic may alter. Therefore, in real-world conditions, a robust plan is required.

In this paper, a new robust mathematical model is proposed to determine Stop-Skipping Patterns (SSP) by defining different but limited number of timetable patterns. Each pattern defines the set of stations that trains stop for boarding and alighting purposes. To illustrate the issue, suppose that there is a set of stations, entitled S. The proposed mathematical model, considering the traffic study as the input data, determines the optimum set $S'_i \subset S,\ i \in \{1, \ldots, N\}$ which specifies the stations that train i is planned to stop. Note that N is the number of patterns. Therefore, train i skips stations belong to set $S_i - S'_i$, and no passengers can board or alight train i in these stations.

* Corresponding author.

http://dx.doi.org/10.1016/j.trc.2015.09.013
0968-090X/

It is necessary to mention that, the stop skipping approach in comparison with conventional all-stop approach results following consequences:

- Increasing the commercial speed.
- Reducing the number of trains in operation.
- Reducing the number of required parking lines, as well as the acquisition costs.
- Saving the used energy through reducing the number of required stops.
- Increasing the passenger's waiting times at non-crawdad stations.

It is worth saying that all parameters in metro systems are designed so that all traffic demands are serviced in a more efficient and at minimum cost. In order to inform the passengers from the exact remaining waiting times, the necessary information is presented through Passengers Information System (PIS) at stations.

1.1. Previous works

During the past decade, the train timetabling problem has gained lot's of researchers' attention, and became one of the most interesting research topics. In this regard, Ghoseiri et al. (2004) introduced a modified B&B algorithm which contains some methods to reduce the solution space in main line railway systems. A new multi objective mathematical model for train scheduling problems in main line railways introduced by Zhou and Zhong (2007). Shafia et al. (2012) proposed a robust timetabling model, and proposed a robustness measure to compute the required buffer intervals. Beside mainline train timetabling problem, in conventional urban transport system, train timetables is easily computed based on the headway distribution. In this method, the required headway during working days is firstly computed based on the traffic study measured by minimum Passenger Per Hour Per Direction (PPHPD) scale, and the headway is computed based on the PPHPD and the capacity of trains.

Recently, a new timetabling approach is developed based on generating fully automatic demand-oriented timetables. Niu and Zhou (2013) proposed a non-linear optimization model, and two heuristic algorithms to determine the departure times of trains at the start terminal, based on the time-dependent, origin-to-destination trip records from the automatic fare collection system, in a heavily congested urban rail corridor. Albrecht (2009) proposed a two level approach to generate demand-oriented timetable, where the optimal train frequency and the capacity of trains are first determined and then the schedule of trains are optimized.

The problem of defining different stop-skipping patterns for vehicles, is practiced in both rail and bus transportation systems. For example, Fu et al. (2003) studied a bus operations control strategy in which this issue applied to every other bus dispatched from the terminal. Nguyen-Duc and Descotes-Genon (2007) proposed a nonlinear mathematical model as well as a simulated annealing algorithm for the real-time stop-skipping problem for the bus urban transportation network. Feng et al. (2013) proposed an optimization model, as well as a genetic algorithm for designing stop-skipping service that can minimize the total travel time for passengers in an urban bus corridor. Liu et al. (2013) proposed a multi-objective mathematical model as well as a genetic algorithm to formulate the stop-skipping scheme for bus transportation rescheduling problem. In railway urban transport system, Sogin et al. (2012) proposed a mathematical model to optimize the stop-skipping service for urban railway systems. Their proposed formulation is similar to a shortest path network problem. They also proposed a genetic algorithm. The proposed model is not considered some main constrains such as minimum headway, as well as the effects of stop-skipping patterns on the dwell times.

Wang et al. (2014) proposed a very detailed non-linear bi-level model of train movements with stop-skipping and the O–D dependent passenger demands, as well as a genetic algorithm. Chang et al. (2000) proposed a multi objective mathematical model which minimizes the operator's total operating cost as well as the passenger's total travel time, using the stop-skipping approach in a high-speed railway line. Then the model is solved by a fuzzy mathematical programming approach. It is worth to mention that, mainline railway lines in opposite of urban railway lines are not usually so much sensitive to the headway alterations, as well as dwell times changes caused by stop-skipping patterns.

1.2. Contribution of the paper

In this paper, a new formulation is developed for the problem of finding the optimum stop-skipping patterns in urban railway systems. The proposed formulation is non-linear that is extended to a linear one by defining some new variables and constraints. As the number of passengers boarded and alighted are not always fixed, and may alter in different events and special conditions, a robust approach is used to reach a more reliable and practical solution. This method offers a more cost-saving and more rapid transport system. Moreover, as the optimum solution could not be found in a rational amount of time, a decomposition-based algorithm and a simulated annealing algorithm are proposed.

1.3. Outline

The current paper is organized as follows: In Section 2 the problem is defined, and the mathematical model is proposed. In Section 3, a robust approach is utilized, and the robust mathematical model is proposed. In Section 4, two new heuristic