JOURNAL OF TRANSPORTATION
SYSTEMS ENGINEERING AND INFORMATION TECHNOLOGY
Volume 13, Issue 5, October 2013
Online English edition of the Chinese language journal

Cite this article as: J Transpn Sys Eng & IT, 2013, 13(5), 72−78, 100.

RESEARCH PAPER

Route Selection for Railway Passengers: A Multi-objective Model and Optimization Algorithm

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Abstract: With an increased operating speed in Chinese railways in recent years, the number of passengers traveling by trains has been significantly increasing. The research issue is regarding how passengers select their routes when there are no direct trains. Previous studies have dealt with the route selection problem as a multi-objective optimization. The study began by setting up a transportation network which encompasses the departure and terminal stations along with important intermediate stations. Then, six key factors are analyzed and formulated using a multi-objective model, consisting of the train-running time, railway fare, transfer frequencies, distances between transfer stations, transfer interval time, and travel comfort. Furthermore, a two-phase algorithm is employed to solve the model. A rapid searching algorithm for feasible routes based on the train timetable is established, then the weight vector is assigned by introducing the information entropy to obtain satisfied routes. In the end, the two-phase algorithm is tested respectively for railway passengers from Lanzhou to Beijing (with direct trains) and from Lanzhou to Changchun (without direct trains), and the results show that the proposed model and solution algorithm are efficient for obtaining satisfactory routes.

Key Words: railway transportation; route selection; multi objective; transfer; information entropy

1 Introduction

The 21st century is an era when the Chinese railroad industry has experienced rapid progression. The train operating speed has increased for the sixth time, and as a result, high-speed railway services are offered for more passenger dedicated lines. A critical research issue is how the passengers traveling by train choose the optimum route.

A significant amount of literature exists regarding to the route selection problem for public transportation passengers. Liu[1] developed a mathematical model and yielded a satisfactory solution based on the maximum travelers' utility. Bi *et al*.[2,3] set up an additional mathematical model using the matrix theory and set theory with minimum transfer frequencies and travel time. Jiang *et al*.[4] analyzed eight items including the minimum one-way time, minimum transfer time, and minimum fare based on the study of passenger options traveling by train. Finally a comprehensive and optimal model of the passenger traveling plan by train through the eight balance coefficients was formulated, and a directive network was established. The corresponding algorithms were also presented. Yu[5] proposed a passenger transfer optimization model based on the utility theory. The theory considered heterogeneous demands of railway passengers and selected the K-shortest-path algorithm to solve the model. Liu and Ni[6] established a transfer network and a transfer model based on the railway timetable by adding virtual points. The transfer model which considered the limited transfer times and the minimum travel time was solved by the genetic algorithm. Wang and Yang[7] established priorities based on individual demand and defined the weighted sum of the factors as a generalized travel-time function. The function considered various factors of passenger transference based on the passenger train timetable. Also, it presented a simple mathematical model of dynamic programming that was then solved by the A* algorithm. Shi *et al*.[8] designed a multi-item Logit model for individual passenger train choice probability and analyzed the factors that influenced the choice. Cui *et al*.[9] provided a method to estimate multi-target weighted values and discussed two solution methods for the shortest path and train matching. This method was accomplished by minimizing

Received date: Sep 27, 2012; Revised date: Dec 11, 2012; Accepted date: Jan 9, 2013
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DOI: 10.1016/S1570-6672(13)60124-5

the sum of travel-oriented and transfer-oriented values.

The route selection problem for railway passengers cannot be simply regarded as the shortest path problem, owing to the fact that different passengers have different understandings as to the optimal traveling routes. Therefore, a multi-objective optimization model is developed with aim of minimizing the train-running time, railway fare, transfer frequencies, distances between transfer stations, transfer interval time and the restoring time. Furthermore, a fast searching algorithm for feasible routes is designed based on simplified railway transportation networks, the train's timetable, and information entropy.

2 Transportation network for railway passengers

In China, there are thousands of passenger transportation stations. Constructing a network which includes all passenger transportation stations would be a time-consuming task. Thus, for the sake of calculation efficiency, a simplified network which encompasses all departure and terminal stations as well as important intermediate stations can be instituted. The intermediate stations that have no train stops or only one train stops will be removed.

The simplified railway passenger transportation network is constructed by assuming passenger stations as nodes, arriving and departing time of passing trains as weights for each node, and trains and their running-time between adjacent stations as edges and weights, respectively. Let $G=(V, L)$ be a directed railway transportation network, and $L=\{l_i|i=1, 2, \cdots, N\}$ be the train set, where N is the number of trains (the up train and down train, counted respectively). Let $V=\{V_{l_i}|l_i\in L, i=1,2,\cdots,N\}$ be the station set, where $V_{l_i}=\{v_{l_i}^1, v_{l_i}^2,\cdots,v_{l_i}^{m_{l_i}}\}$ is the station set passed by train l_i and $T_{l_i}=\{(t_{l_i}^1(s), t_{l_i}^2(s))|s\in V_{l_i}\}, l_i\in L$ be the time set of train l_i, where $t_{l_i}^1(s)$ is the time when train l_i arrives at station s (hereafter, arriving time) and $t_{l_i}^2(s)$ is the time when train l_i departs from station s (hereafter, departing time). Let $C=\{c_{l_i}|l_i ? L\}$ be train category set and $P=\{p_{ij}(l_i)|i,j\in V_{l_i}, l_i\in L\}$ be train ticket price set, where $p_{ij}(l_i)$ denotes the ticket price from station i to j by train l_i, let $V^t=\{(v_{l_k}^i, v_{l_m}^j)|v_{l_k}^i, v_{l_m}^j\in V\}$ be the set of all transfer-station pairs, where $(v_{l_k}^i, v_{l_m}^j)$ denotes that passengers, if necessary, can transfer from train l_k to train l_m through transfer-stations $v_{l_k}^i$ and $v_{l_m}^j$, which are the same stations or in the same city. Let $D=\{d(v_{l_k}^i, v_{l_m}^j)|(v_{l_k}^i, v_{l_m}^j)\in V^t\}$ be the transfer-distance set, where $d(v_{l_k}^i, v_{l_m}^j)$ denotes the distance between the pair of transfer stations $v_{l_k}^i$ and $v_{l_m}^j$.

3 Multiple factors in the route selection process

As compared with other factors, the following six are often regarded as the most important during the railway passengers' route selection process: the train-running time, railway fare, transfer frequencies, distances between transfer stations, transfer interval time, and travel comfort.

3.1 Train-running time

Let $t_{ij}(l_i)$ be the running time of train l_i from station i to j, which can be further expressed as Eq.(1).

$$t_{ij}(l_i)=t_{l_i}^1(j)-t_{l_i}^2(i) \tag{1}$$

3.2 Railway fare

Railway fare is varied among different types of trains and different seats of trains. In China, there is the electric multiple unit (EMU) train, the direct express passenger train, the express passenger train, the fast speed passenger train, and the general fast train. Railway passenger ticket fares between two stations of any train can be easily found from the passenger train timetable. Here, the lowest ticket fare was chosen for calculations. As defined above, the ticket fare of train l_i from station i to j can be expressed by $p_{ij}(l_i)$.

3.3 Transfer frequencies

Transfer frequencies are the number of times that railway passengers transfer between trains. Generally, if the train-running time is similar, passengers are more likely to select routes with lower transfer frequencies[10]. Moreover, transfer frequencies are intended to be small due to long train-running time and exhaustion with fatigue. Here, $N_{\max}$ is defined to be the maximum transfer frequency.

3.4 Distances between transfer stations

As previously mentioned, there are two cases referring to the distances between transfer stations. The first case is that transfer stations $v_{l_k}^i$ and $v_{l_m}^j$ are different stations but located in the same city, and the second is that they may be the same station. For the convenience of calculation, we define $d(v_{l_k}^i, v_{l_m}^i)=0$ under the later circumstance.

3.5 Transfer interval time

Transfer interval time is the time required to transfer from train l_1 to l_2, which is the interval between arriving time of train l_1 and the departing time of train l_2. However, if the transfer interval time is less than the standard time, T_0 (normally T_0=20 min)[9], passengers are likely to miss train l_2, and forced to wait, thus adding the interval time from train l_1 to l_2 by 1,440 minutes. Thus, $t_{ij}(l_1, l_2)$, the transfer interval time from train l_1 at station i to train l_2 at station j, can be described as Eq.(2).

$$t_{ij}(l_1,l_2)=\begin{cases} t_{l_2}^2(i)-t_{l_1}^1(j), & t_{l_2}^2(i)-t_{l_1}^1(j)\ge T_0 \\ t_{l_2}^2(i)-t_{l_1}^1(j)+1440, & t_{l_2}^2(i)-t_{l_1}^1(j)< T_0 \end{cases} \tag{2}$$

Long transfer interval time entails high cost for passengers due to room and board fees. While short transfer interval time causes high risks for passengers due to the random variation of train operation. Typically, passengers allow three to five hours to transfer between trains. Therefore, the evaluation functions for $t_{ij}(l_1, l_2)$ can be defined as Eq.(3).