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Research on Urban Rail Transit Network Based on Optimization Model

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Abstract

In this paper, in order to solve the situation of overloaded passenger flow and crowded passenger flow, we have formulated a scientific and reasonable passenger travel optimization scheme and rail traffic flow restriction scheme. Specifically, we use statistical knowledge to obtain the travel time distribution and travel duration distribution of passengers, respectively. We use the Floyd algorithm to calculate the shortest distance traveled by passengers. In addition, we design a set of path planning algorithms with the shortest travel time by using the distance method instead of the distance between adjacent stations, and use the Topsis algorithm to generate the congestion score matrix of each station. Finally, a multi-objective current-limiting optimization model is established by setting different numbers of current-limiting stations at different stations, and a current-limiting model of Batong line is established, and the optimal solution of the current-limiting model is obtained by using the simulated annealing algorithm.

Keywords

Floyd, Topsis, path planning, multi-objective optimization, intelligent algorithm, simulated annealing algorithm.

1. Research Background

With the rapid development of urban rail transit, rail transit in major cities has gradually become an essential means of transportation for urban residents to travel daily, providing strong support for the development of cities and an indispensable and important part of urban transportation.

Firstly, the data is preprocessed, and the preprocessed relevant data is used, combined with the train operation map data of each time period to carry out the next research. It is necessary to count the number of passengers traveling in different time periods, distances, and durations. For the travel distance of passengers, it is considered that under normal circumstances, passengers choose the shortest route, so the Floyd algorithm is used to solve the shortest distance between the departure and destination of a given passenger as the travel distance of passengers [1]. According to the statistical results, draw a line graph of the distribution of the number of passengers traveling in different time periods, and a histogram of the number of passengers with different travel distances and travel durations to describe the travel characteristics of passengers.

Secondly, we replace the distance between neighboring sites with time apart. The Floyd algorithm is used to automatically plan the path with the shortest travel time, and at the same time, according to the time of passengers entering and leaving the station, and then according to the train schedule, the closest outbound and inbound trains are matched as passenger trains and arriving at the terminal. At the same time, in the actual boarding process, it is necessary to consider the difference in the passenger flow of different stations at different times. Sometimes

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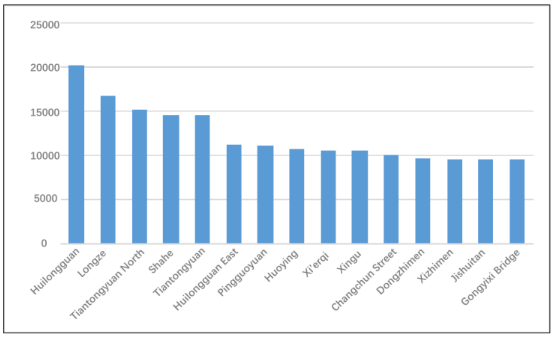
the waiting cost of choosing the shortest route may be higher, resulting in the shortest route. The travel efficiency is not the highest. Two factors are mainly considered when setting the intelligent optimization algorithm. The congestion probability of different stations in a specific time period. Taking the above two factors as indicators, the corresponding weight matrix [2] is generated, and the corresponding weight matrix is added to the original algorithm to realize the automatic planning of the optimal travel path.

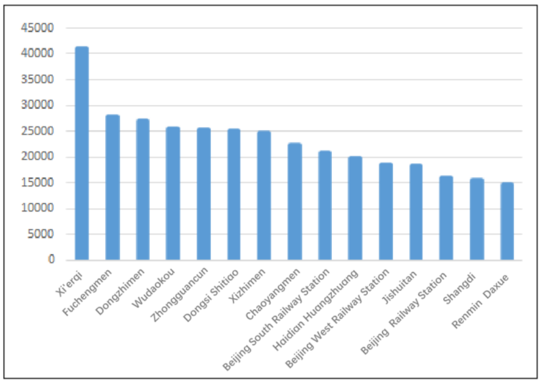
Finally, it is necessary to analyze the current limiting effect of different stations on the Batong line. The full-load capacity of each train on Batong line is 1,428 people. In the daily operation process, the train may be overloaded, and the overload of the train will greatly increase the risk of train operation. However, the maximum number of passengers on the train can ensure that passengers have more High travel efficiency. In order to make people's travel as efficient as possible without overloading the train. Therefore, on the basis of comprehensive consideration of factors such as transportation capacity and passenger flow demand, a multi-objective optimization model is established to minimize passenger retention time and passenger travel time by setting different numbers of current limiting stations at different stations. The algorithm solves the problem, taking into account the optimal planning of the subway system and passenger demand.

2. Floyd Algorithm

We select a specific time to conduct a preliminary statistical analysis on the outbound and inbound situations of different stations, and obtained the top 15 stations in the number of inbound and outbound passengers of all subway stations in Beijing within a given time period, as shown in Fig. 1 (a) and (b).



a The site with the TOP15 people entering the station



b Sites with TOP15 outbound numbers

Figure 1 Sites with TOP15 inbound and outbound numbers (x-axis: different stations; y-axis: total number of people)

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From Fig.1, it can be seen that the number of people entering the station in Huilongguan, Longze, and Tiantongyuanbei all exceeded 15,000. According to preliminary analysis, these areas should be the main residential areas for office workers.

By analyzing the passenger flow of different lines in Beijing, the number of people entering and leaving the station on different lines can be obtained as shown in Fig.2.

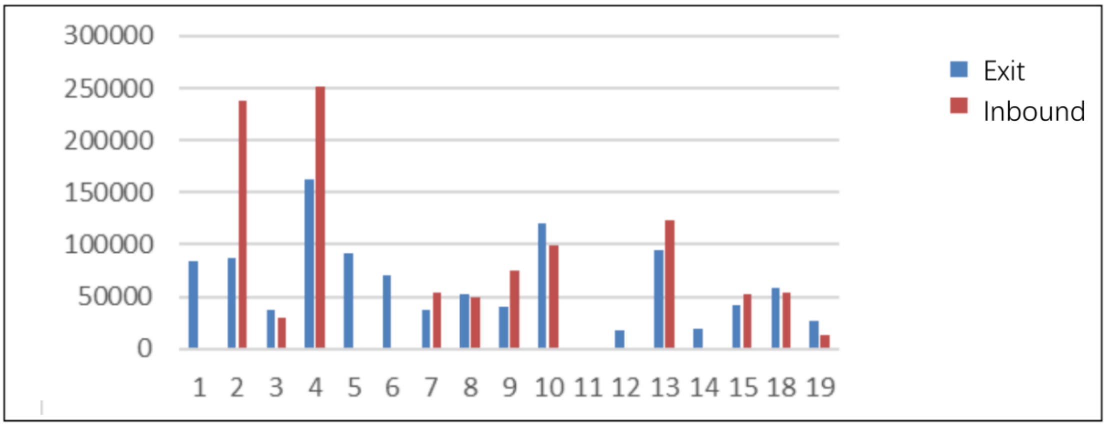
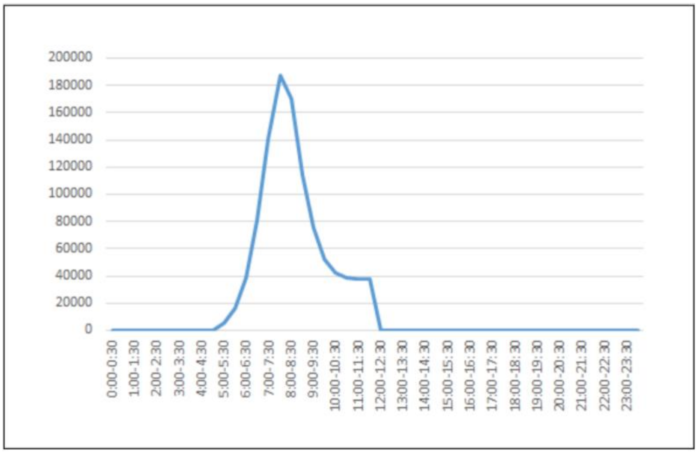
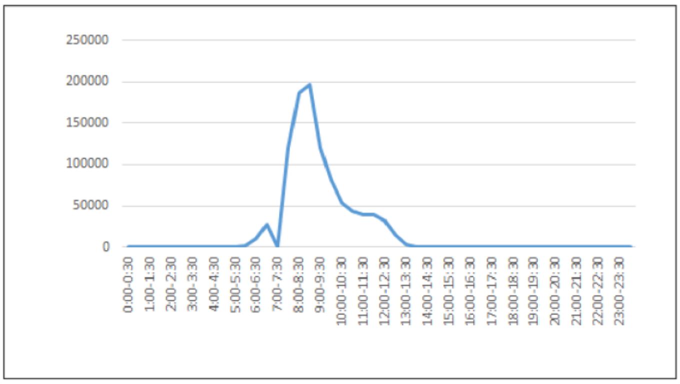


Figure 2 Number of people leaving and entering stations on different subway lines (x-axis: subway lines; y-axis: total number of people)



a Line chart of the frequency distribution of pit stops



b Line chart of outbound frequency distribution

Figure 3 Line chart of frequency distribution of inbound and outbound stations (x-axis: time period; y-axis: total number of people)

As can be seen from Fig. 2, Line 2 and Line 4 have the largest number of people entering the station. Metro Line 2 surrounds the central urban area of Beijing, and the stations experienced are the core areas of Beijing. Line 4 ranks first in both the number of outbound and inbound

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numbers. This line runs through the north and south of Beijing and belongs to the main line between the north and south of Beijing. This line effectively shares the rail transportation pressure in the central city.

For the analysis of the travel period, the research is mainly carried out from the two dimensions of inbound and outbound, and the results are shown in Fig. 3 (a) and (b).

It can be seen from Fig. 3 that from 7:00 to 9:00 is the morning rush hour, and the number of people entering the station is the largest. Considering this period as the commuting time period for office workers. After nine o'clock, the number of people entering the station gradually decreased to ten o'clock and gradually stabilized. The highest peak of outbound is from 8:30 to 10:00, and the main reason is that the crowds in the morning peak arrive at the workplace. Comparing with the inbound peak period, the outbound peak period has a significant lag effect, which is also in line with the actual commuting situation in the morning peak.

On the premise of known departure and arrival stations, Floyd's algorithm [1] is used to solve the shortest distance. Floyd's algorithm is an algorithm to solve the shortest path between any two points, which can find the shortest path between any two points at one time. A diagram of the shortest distance is shown in Fig. 4.

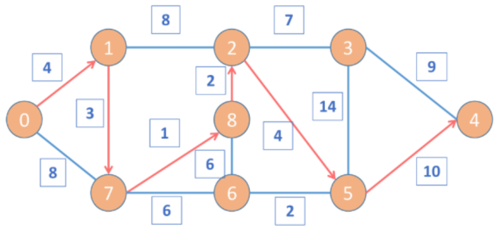

Figure 4 Schematic diagram of the shortest distance

Finding the shortest distance between stations using an iterative formula, which can be expressed as:

$$A_k(i,j) = \min(A_{k-1}(i,j), A_{k-1}(i,k) + A_{k-1}(k,j)) \quad (1)$$

where $A_k(i,j)$ represents the shortest path length of the station sequence number not greater than k on the path from station v_i to station v_j, k is the number of iterations.

When k=n, the solved distance matrix is the shortest distance value between the vertices, and finally the shortest distance traveled by passengers is obtained as the travel path of passengers. The distribution diagram of travel distance is shown in Fig.5.

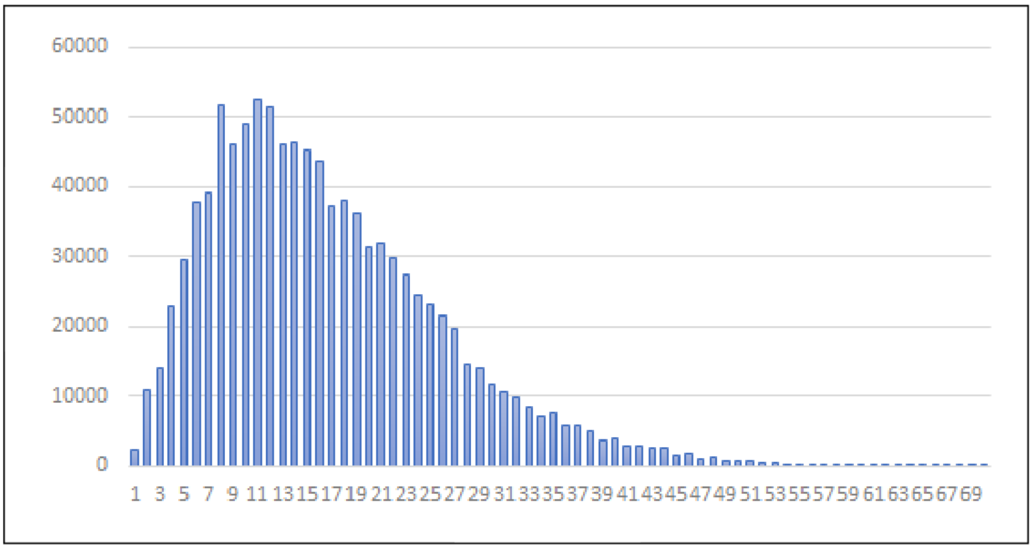

Figure 5 Travel distance distribution map (x-axis: traveling distance, unit: km; y-axis: total number of people)

It can be seen from Fig. 5 The travel distance of the majority of passengers is basically distributed between 5km and 20km, which is consistent with the actual commuting distance of large cities, but there are still a few passengers whose travel distance is greater than 30km. Considering that it may be the office workers living in the suburbs who go to work in the central city during the morning rush hour work.

By analyzing the correlation, since the passenger's arrival time and departure time are given in the passenger's OD data table, the difference between the two can approximately replace the passenger's travel time, and the passenger's travel time distribution is obtained as shown in Fig. 6.

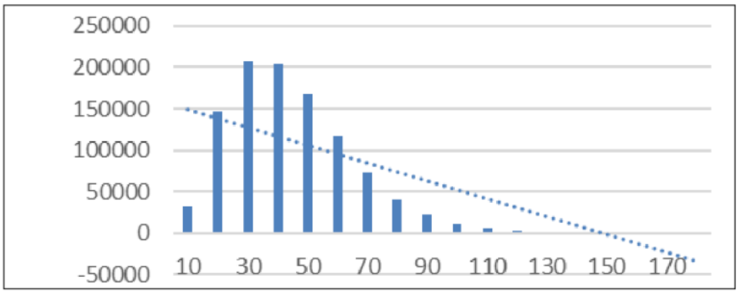

Figure 6 Travel time distribution map (x-axis: traveling time, unit: minute; y-axis: total number of people)

It can be seen from Fig. 6 that the commuting time of most passengers is concentrated in 20-60 minutes, and the commuting time is most concentrated in 30-40 minutes. There are very few passengers with commutes longer than two hours, which corresponds to the distribution of travel distances.

3. Intelligent Optimization Algorithm

The generation of the weight matrix mainly considers three indicators: the number of outbound people, the number of inbound people, and the degree to solve. First, the scores of the number of people leaving the station, the number of people entering the station, and the degree, that is, the score of the crowding degree, are calculated, and then the original data is weighted. For the generation of the weight matrix, we mainly consider using the Topsis analysis method to obtain the corresponding weight. We have 328 evaluation objects (each subway station) and 3 evaluation indicators (number of people leaving the station, number of people entering the station, degree), so we need to construct a 328×3 evaluation matrix.

Forwarding processing of outbound numbers:

$$x_{ij} = max - x_{ij} \tag{2}$$

Standardizing each value in the evaluation matrix:

$$z_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2} \tag{3}$$

Defining the distance between the i-th (i=1,2,3,...,n) evaluation object and the maximum value as:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} (z_j^+ - z_{ij})^2} \tag{4}$$

Defining the distance between the i-th (i=1,2,3,...,n) evaluation object and the minimum value as:

$$D_i^- = \sqrt{\sum_{j=1}^{m} (z_j^- - z_{ij})^2} \tag{5}$$

The unnormalized scores of the indicators corresponding to each object:

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$$S_i = \frac{D_i^-}{D_i^- + D_i^+} \tag{6}$$

We normalize the index score of each object to get the final normalized score:

$$\widetilde{S_i} = S_i / \sum_{i=1}^{n} S_i \tag{7}$$

4. Batong Line Current Limiting Model

Taking the Batong Line as a single line of urban rail transit, the corresponding objective function is established, considering the dynamic change of passenger flow, so as to minimize the passenger's stay time and travel time, and finally achieve the optimal of the two.

The number of restricted passenger flow at station m in time period t is denoted as can be expressed as:

$$w = (U_m^t - \overline{U_m^t}) \cdot \Delta t \tag{8}$$

where Δt represents the time period of length , and the objective function of the total residence time in the flow-restricted time period of all stations on a single line is:

$$\min \sum_{m \in M} \sum_{t \in T} (U_m^t - \overline{U_m^t}) \cdot \Delta t \tag{9}$$

The multi-objective optimization model is obtained as follows:

$$\min \sum_{m \in M} \sum_{t \in T} \left(U_m^t - \overline{U_m^t}\right) \cdot \Delta t;\ min \sum_{l \in \in L} \sum_{t \in T} C_1^t \cdot h_1 \tag{10}$$

In order to solve the optimization problem, we intend to use simulated annealing [6] to find the optimal solution of the model. The specific solution method is shown in Figure 7.

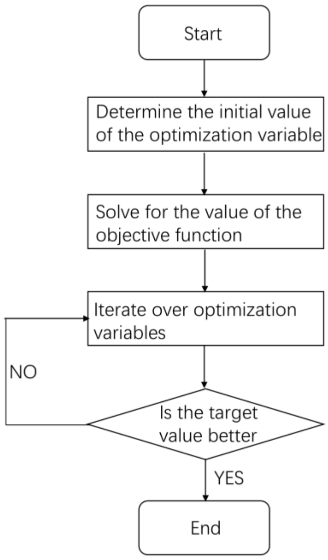

Figure 7 Model solution flow chart

If there is no restriction on the current-limiting stations, the first 9 stations are selected as the current-limiting stations, and the results of the total travel time and average travel time before and after the corresponding current-limiting based on the above algorithm are shown in table 1.

Table 1 Unlimited number of stations on Batong line

Contrast	Total travel time (T(min))	Average travel time (T(min))
Before current limiting	2431952.7635	34.91414707
After current limiting	2223071.4356	31.92996837
Difference	208881.3279	2.984178701
Percent reduction	8.59%	8.59%

It can be seen from table 1 that Shuangqiao and Baliqiao are the two stations with the best current limiting effect. The main reasons are as follows: Shuangqiao and Baliqiao are the two stations with relatively large demand for passengers entering the station. Through the solution of the current limiting model of the current limiting station, the two stations of Shuangqiao and Baliqiao are the two stations with the best current limiting effect. Tuqiao is the starting station of Batong line, which carries a large passenger flow. Due to the forward influence relationship between stations, if the passenger flow of Tuqiao station is too large, it will have a greater impact on the subsequent stations.

Considering the number of current-limiting stations on the Batong line, adjust the parameters of the number of current-limiting stations, and use the above model to solve the total travel time and average travel time before and after the current limit. The results are shown in table 2.

Table 2 Analysis of current-limiting stations on Batong line

Contrast	Number of traffic-restricted stations: 1	(Baliqiao Station	Number of traffic-restricted stations: 2	Guoyuan and Guanzhuang stations
	Total travel time (min)	Average travel time (min/person)	Total travel time (min)	Average travel time (min/person)
Before current limiting	2431910	34.91414707	2431910	34.91414707
After current limiting	2224050.01	31.92996837	2386674.1	34.26471068
difference	207859.983	2.984178701	45235.842	0.649436394
percentage	9%	9%	2%	2%
Contrast	Number of traffic-restricted stations: 3	Tuqiao, Orchard, Guanzhuang Station	Number of traffic-restricted stations: 4	Tuqiao, Liyuan, Tongzhou Beiyuan, Baliqiao Station
	Total travel time (min)	Average travel time (min/person)	Total travel time (min)	Average travel time (min/person)
Before current limiting	2431910	34.92370754	2431910	34.91414707
After current limiting	2353482.32	33.78818623	2347071.3	33.6961461
difference	78427.6760	1.125960836	84838.639	1.218000966
percentage	3%	3%	3%	3%
Contrast	Number of current-restricted stations: 5 (Tuqiao, Linheli, Liyuan, Guoyuan, Baliqiao Station)			
	Total travel time (min)		Average travel time (min/person)	
Before current limiting	2431910		34.91414707	

After current limiting	2327328.37	33.41270249
difference	104581.620	1.5014458
percentage	4%	4%

It can be seen from table 2 that the current limiting effect of timely adjustment is better than the single fixed current limiting effect. The smaller the length of the current-limiting period, the better the current-limiting effect, and 30 minutes is the most suitable choice in the actual solution process. With the increase in the number of limited-flow stations, the congestion in the stations has been alleviated, and the congestion in the trains has also decreased accordingly. But it is worth noting that the increase in the flow restriction will lead to an increase in the overall stay time of passengers. According to the actual situation, the time period of the current limit can be considered reasonably staggered during the peak period when the number of travelers is large, so as to reduce the passenger's stay time.

5. Conclusion

In this paper, we use the Floyd algorithm to calculate the shortest distance traveled by passengers. In addition, the Topsis algorithm is used to generate the congestion degree score matrix of each station, and the travel time is weighted to obtain an intelligent algorithm for path planning with the shortest travel time. Finally, a multi-objective flow-limiting optimization model is established by setting different numbers of flow-limiting stations at different stations. Taking the minimum sum of the passenger's stay time and the shortest travel time as the two target values, the full load of the vehicle, the passenger flow and the station's transport capacity are the two target values. Constraints and other conditions are the constraint values, the current limiting model of the Batong line is established, and the optimal solution of the current limiting model is obtained by using the simulated annealing algorithm.

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