Passenger Flow Analysis of Direct Metro Lines

Xue-wen TAN¹,*, Fan YANG¹ and Xiao-zhou CHEN²

¹School of Mathematics and Computer science, Yunnan Minzu University, Kunming 650500, China
²Key Laboratory of IOT Application Technology of Universities in Yunnan Province, Yunnan Minzu University Kunming, China 650500

*Corresponding author

Keywords: Travel time distribution, Multiple linear regression, Passengers flow.

Abstract. The metro or subway has become a preferred plan for going out, hence the pressure of urban traffic has been put on metro or subway. Based on the original metro network, we designed some through train to optimize the operation efficiency of the whole metro network and the social benefits brought by it. Meanwhile we shorten the travel time of long-distance passengers; on the other hand, we decrease the intermediate site traffic pressure. We separately pick up the possible metro line of the whole metro network as analysis object, through choosing a fixed range at the two ends of the line as the data object model analysis. Using Poisson distribution and multiple linear regression analysis to calculate the direct passenger flow rate between the two stations, then we get the direct passenger flow rate in the selected range of traffic between two stations, and select the two stations that has the maximum of those rate as the result of terminals. Considering the passengers’ waking-time, waiting-time and journey time, we can get the passengers’ travel time by algorithm analysis. And using the passengers’ travel time as test model reference quantity of model test, and reducing the travel time can directly improve the social benefit and economic benefit.

Background of Research

With the urbanization and increased population, they no longer meet the requirements of travel. City problems result from increased vehicles, such as heavy traffic, travel difficulties, serious air and environmental pollution and so on. In order to solve these problems, the rail transit appears. The construction of urban rail transit is the first choice for many cities to solve the problem. Rail transit has plenty advantages such as large transport capacity, low cost, less pollution, economy, safety, high efficiency, less covers and etc. Rail transition brings great convenience for people's travel and gains more popular. As an important part of city rail traffic, the subway makes great contributions to people’s travel, working, shopping and tourism. Compared to the bus, subway has the following features like fast, convenient, comfortable, no traffic jams, punctuality and etc. At present, the operation mode in many cities is that the subway stops at every station from starting station to terminal. So that all the passengers along the subway track can be easily transport. But for the current big city subway network, it is usually take a long time to transport passengers in a far distance between two stations, which greatly reduced the passenger travel experience. In order to limit the time, we suggest setting up the shuttle bus between the two long-distance stations to save time.

Research Dynamic

At present, the research on the design of subway route direction has been developed. In the references[1], influence factors of site selection of urban subway station were analyzed, then locations were established, and take the subway as an example. The article[2] introduces the design of the first domestic direct bus, which lays the foundation for the design of the railway direct line. The paper[3] introduces the design of the Metro timetable system and optimization of design scheme, knowing the design of the railway direct line in a certain degree.
Research on Contents and Thought

Between the current large urban subway network, usually take a long time to transport passengers between two stations away from the station. This greatly reduced the passenger travel experience. In order to reduce passengers from the starting point to the terminal time, we can recommend a direct train between the two long-distance stations to save time. The research contents of this paper are as follows: design a mathematical model to optimize the selection of the starting station and terminal, and evaluate the expected results; explore the advantages that may be achieved by adjusting the distance between trains or establishing a special direct line to achieve maximum economic and social benefits.

We adopt two ways of thinking. Method one: the data were processed by regression method, and then the regression coefficients were compared. Finally, the starting station and terminal were gained. Method two: analyze the number of the get on and get off each site to find the highest direct rate between the two sites, which determine the starting station and terminal. Direct rate is from the station to the direct passenger flow and stand to the ratio of the passenger flow. The higher the direct rate between the two sites can be used as a starting point and terminal station. The starting point of the direct line is not necessarily the starting point of the subway line, the terminal station of the direct line is not necessarily the terminal station of the subway line. Through our team leader's programming simulation, we confirmed that the mathematical model of the design to a certain extent, can solve the starting point and terminal point of choice. We use analytic hierarchy process and the optimization thought to establish the model of subway traffic line and the main mathematical formula of the train is introduced. In order to maximize the social benefit and economic benefit, by analyzing subway operating regulations, waiting time-satisfaction function and travel time-satisfaction function were set up to evaluate the subway line social benefits, meanwhile, business cost function was set up to evaluate the economic benefits of direct rail line. Finally, the mathematical model is verified by the related data compilation program. The results show that our model can achieve social and economic benefits. But there are still some deficiencies between the best results.

Research on Model

Subway passengers travel time is the shortest, travel time T represents the elapsed time from the point A to point B. Including the time from the place of departure to the subway station, the waiting time, and the subway time. The equation is

\[ T = \sum_{i=1}^{n} T_{ij} \cdot m_{ij} \quad m_{ij} \in \varnothing \]  

(1)

\[ T_{ij} = \theta_1 \cdot t_1 + \theta_2 \cdot t_2 + \theta_3 \cdot t_3 + \theta_4 \cdot t_4 \]  

(2)

\[ t_1 = \frac{\sqrt{S_i}}{uv} + \frac{\sqrt{S_j}}{uv} \]  

(3)

\[ t_2 = \eta \cdot (0.5 + \alpha) \]  

(4)

\[ t_3 = \eta \cdot (0.5 + \alpha) + t_0 \]  

(5)

Here T represents the passenger’s travel time. \( T_{ij} \) indicates the passengers total travel time from i to j, \( m_{ij} \) denotes the total number of passengers from i to j. \( \theta_i \) represents the time constant, \( i = 1,2,3,4 ; t_1,t_2,t_3,t_4 \), respectively, that passengers walking time to the subway station, the time to
wait for the subway, transfer time and travel time; \( S_i, S_j \) respectively, show the area of the cell \( i, j \), \( V \) is the average walking speed, \( u \) indicates the parameter value related to the density of the metro, generally take 2-4. \( \eta \) is the intervals of Subway’s departure time; \( \alpha \) is the average retention rate; \( t_0 \) indicates the transfer time; \( V_0 \) says the average speed of the subway.

**Passenger Flow Classification and Property Analysis**

On the subway line cross-section passenger flow, according to the location can be divided into distance section passenger flow \( P_d \) and station section passenger flow \( P_s \). Interval cross-section passenger flow also known as the number of passengers, in the interval section of the passenger flow the passenger flow was observed throughout the time all day long; a section of passenger traffic remains the same in a period of time between two stations. Inter-section passenger flow in a period of time can be more intuitive to reflect the imbalance of the passenger flow’s space and direction. Each section of passenger traffic \( P_e \) corresponds to an interval or two stations in a distance. Passenger flow at the station section \( P_s \), observed the traffic at the station section at all times during the day: the section of passenger traffic stay the same in a period of time. Passenger flow keep changing as the passengers continue to change on and off, from the rear section of the passenger section into the front section of the passenger flow, so there are generally two ways: the rear section of passenger flow in the station or the front section.

**OD passenger flow,** \( P_{od} \), also known as passenger flow of the starting point, said the passenger flow from O station to D station, generally by the passenger point difference, in the form of passenger flow matrix: urban rail transit OD passenger flow table can directly reflects the distribution of direct passenger flow, indirectly reflects the passengers’ riding distance and passengers’ turnover.

Set a city rail transit network is Total \( n \) stations

\[
P_e = \sum_{od} P_{od}
\]

(6)

In the equation, distance section passenger flow, passenger flow \( P_{od} \). Distance section passenger flow and the number of people up and down the station.

\[
P_{e_{(x,x+1)}} = P_{e_{(x-1,x)}} + P_{up}^x - P_{down}^x
\]

(7)

The number of people up and down the station \( P_{up} \), \( P_{down} \), \( X(i,j) \) is the number of passengers getting on at the station \( i \), getting off the bus at the station \( j \), (i.e., the number of OD): \( Y(i,j) \) is the number of passengers who got on the bus at the station \( i \) passed the station \( j-1 \) then stopped at the bus stop \( j \). \( N(j) \) for passengers in the car when the bus passing the \( j-1 \) station, to reach the \( j \). Then for the \( j \) station:

\[
Y(i,j) = Y(i,j-1) - X(i,j-1)
\]

(8)
\[ N(j) = \sum_{i=1}^{\infty} Y(i, j) \]  

The number of people got off the bus is \( B_j \), passengers from the first 1, 2 ... station are likely to get off at the station \( j \), according to the balance of power conditions:

\[ B_j = \sum_{i=1}^{\infty} X(i, j) \]  

According to the passenger travel distance obey the law of Poisson distribution. Getting on the train station 1, 2, ..., passengers still on the bus on the station \( j \) will get off in accordance with their different probability, you can get:

\[ X(i, j) = B(i, j)P*(j-1)Y(i, j) + \left( \sum_{i=1}^{\infty} P*(j-1)Y(i, j) \right) \]  

Here: \( P*(j-1) = \frac{\lambda^{j-i}e^{-\lambda}}{(j-i)!} \frac{\lambda^{i-j}e^{-\lambda}}{(j-i)!} \), \( j-i \) is the number of stations from \( i \) to \( j \). According to the number of passengers up and down passenger, bus matrix \( OD \) can be calculated and accumulated.

**Maximum Passenger Flow and Rate of Direct Subway**

Priority when passengers take subway is the travel time and whether need to change, by using direct traffic as the target, considering the straight line function and the accessibility of subway network as constraints, and take the line length as constraints, using direct traffic as the target to establish objective function:

\[ MaxD_{eq} = \frac{\sum_{i=1}^{n} q_{ij}}{\sum_{j=1}^{n} T_{ij}} \quad j = (1, 2, 3, \ldots, n) \]  

where \( D_{eq} \) is Direct passenger flow, \( q_{ij} \) is Direct passenger flow between node \( i \) and \( j \), \( T_{ij} \) is Network node set.

Maximum passenger flow rate: to ensure it keep maximum, we need to measure the average degree of passengers to transfer coefficient, which is relatively low, the average passenger transfer coefficient for the change to the subway passengers and the sum of travel by subway passengers

\[ Maxv = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} S_{ij} \cdot x_{ij}}{\sum_{j=1}^{n} \sum_{i=1}^{n} t_{ij}} \]  

Where \( v \) represents passenger direct rate, \( S_{ij} \) represents a direct traffic flow from the node \( i \) to \( j \), \( x_{ij} \) represents decision variables. If the starting point \( i \) match with the end point \( j \), \( x_{ij} = 1 \). Otherwise, \( x_{ij} = 0 \). \( t_{ij} \) represents passenger flow from node \( i \) to \( j \).

Based on the calculation results, in the data, we selected the University City station and South Station as the terminal station. Direct drive train between South Station and University City Station, according to the model, the travel time of passengers is calculated: \( T_b = 56.43 \text{min}, T_a = 39.22 \text{min} \).

**Conclusion**

In the current subway network between large cities, it usually take a long time to transport passengers with relatively distance two stations, through the two bus station can set up direct subway to save passengers time. The first question introduced the biggest passenger flows to direct arrival subway.
and rate of the highest mathematical model to determine the direct line of departure and terminal. Further, put forward the suggestion and evaluation with the ideas of the scheduling to solve direct line terminal most crowded around problems. The second question introduced the idea of hierarchy analysis method and optimization, the purpose was established the direct line model.

Subway operation routines were analyzed through using the related mathematics formula. Setting up the social economic benefit model and evaluating comprehensively, there are a certain practical significance to actual direct the design of subway.

Acknowledgement

This research was supported by National People's Committee education reform project (Practical teaching reform of mathematical modeling in Universities for Nationalities under the background of big data) and Yunnan Minzu University education reform project (The research of university mathematics teaching reform and the cultivation of innovative talents under the Internet plus).

References