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The Adjustment Method of Bus Lines along New Subway after Operation

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Abstract

In order to adapt to the passenger demand after urban subway new line operation, and improve the operational efficiency of the bus lines along subway, the adjustment method of bus lines is studied. Taking the HuangHe Rd. segment with Dalian Metro Line 2 as the research object, the passenger volumes of every main traffic mode before and after subway operation were investigated respectively. By mathematical statistics method, the characteristics of passenger volume transferring among the bus, car and subway before and after operation were compared and analyzed. Based on the theory of random utility, not only the Logit model of traffic mode selection before and after subway operation was constructed, but also the calibration method of model parameter was proposed. The adjustment method of bus lines along subway was proposed. The calculation and analysis of application in the case was also conducted. The research indicates that, after subway operation, the passengers undertaken by car and bus along the subway will be attracted by subway to some extent. To adjust the bus lines according to the characteristic of passenger transferring can improve the operational efficiency of the bus lines along subway.

Keywords

traffic engineering, bus, lines adjustment, passenger flow transferring, Logit model, passenger demand

1 Introduction

As the problem of traffic congestion in urban of our country is becoming more and more serious, more and more urban subway system with different scale are planned and constructed. However, once new subway lines start to operate, the travelling mode structure of residents along it will be changed, as Mouronte and Benito (2012) studied. The passenger partaken by car and bus originally will transfer to subway to different extent after its operation, as the studies of Ma et al. (2007) and Ma et al. (2013). This will lead to the decrease of passenger volume partaken by original bus lines, as well as its operational efficiency. In view of this, it is necessary to contrast and analyze the characteristic of passenger volume transferring of every main traffic modes before and after urban subway operation, so as to study and propose the adjustment method of bus lines along subway.

To date, foreign scholars have studied a lot about feeder bus in this field. Incipiently, Verma and Dhingra (2005) discussed the route generation algorithm of feeder bus in the planning framework of urban comprehensive transportation. In this algorithm, after the initial shortest path set is generated, the optimal solution can be searched using the Genetic Algorithm. Thus, the optimal route of feeder bus from every subway station to the terminal can be acquired. In respect of conventional bus and Bus Rapid Transit (BRT), Akin (2006) studied the problem of integration for bus line after railway operation. They proposed an estimation model for passenger flow increment led by railway operation. According to the result of actual application, after lines integration of 11 bus lines and 3 mini-bus lines, the passenger capacity was increased from 28 % to 56 %.The operational efficiency of public transportation system was also increased. In recent years, combining multiple variants of the traditional vehicle routing problem, Abdelgawad and Abdulhai (2012) proposed a routing and scheduling model. By this model, they also calculated the evacuation capacity of subway and bus transit. Based on the passenger flow survey, Duduta (2013) analyzed the application effects of the direct passenger flow model for BRT under the condition of subway operation.

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According to passenger analysis, Verma et al. (2016) designed sustainable metro feeder bus routes and service frequencies. In order to determine the best flow of routes and minimum amount of feeder bus, Vanany et al. (2016) proposed a Genetic Algorithm based approach to develop feeder bus routing model. In order to reduce the usage of private vehicles, using the method of Route Analysis by Tranetsim 0.4, Nur'afalia et al. (2018) obtained the optimal feeder network route that integrates with BRT. Domestically, taking the maximum efficiency of bus network and passenger volume of urban subway, the minimum average cost of passenger and operation and the minimum number of vehicle as optimization objectives, Sun et al. (2014) constructed the multi-objective optimization model of adjustment for bus network. They not only proposed the optimization and adjustment method of bus network based on urban subway new line, but also verified the method by case analysis. Based on the relationship between subway and bus, Zhang and Li (2014) constructed the traffic mode selection Logit model. Using the survey data of passenger volume in Shenzhen, the case was analyzed. The result indicates that the passenger volume partaking rate of subway increases gradually, and that of bus decreases with the increase of collinear distance. By defining the potential demand of feeder bus services and considering its relationship with the traffic demands of corresponding areas, the distance between road and subway, and the repetition factor of bus lines, Zhu et al. (2017) established a demand model of roads by opening feeder bus services and applying a Logit model for passenger distribution.

Although several studies on this topic, in general, have been carried out both here and abroad, most of them abroad focused their attention on the optimization and adjustment of feeder bus network which service for railway transit rather than the urban conventional bus system. The emphasis of their research is the problem of bus feeding around the area of railway station. Domestic scholars focused on the optimization model and algorithm of bus network. However, there are few researches on the characteristic of passenger transferring to solve this problem. Although some scholars have tried to use Logit model to analyze the characteristic of passenger flow, the transferring regular of car passenger is neglected. Given this status in literature, in this paper, based on actual investigation of passenger volume before and after subway operation, the characteristic of passenger transferring of every main traffic mode is contrasted and analyzed. By constructing the Logit model of traffic mode selection, the adjustment method of bus lines along subway is proposed. There will be significant theoretical significance and practical application value to be found when forecasting passenger volume and adjusting bus network.

2 Passenger flow investigation

2.1 The locations

Selecting Huanghe Rd. segment (from Hongqixi Rd. to Xi'an Rd.) with Dalian Metro Line 2 as investigation object, the investigation of passenger volume was carried out. This road segment is 5.8 km long with 6 lanes in two directions. There are 6 subway stations in Metro Line 2. This road segment is one of the most important passenger flow corridor of public transit in Dalian with several bus lines. At present, there are 9 bus lines along this road segment, as shown in Fig. 1. In addition, the car traffic volume is relatively large at morning and evening peak hours. So the proportion of travelling by car should not be ignored. In view of the phenomenon of passenger flow transferring from bus and car to subway after subway operation, the road segment is suitable for this study.

2.2 The time

In order to compare and analyze the changes of the passenger flow partaking volume of every main traffic mode before and after subway operation, and then explore the characteristic of passenger transferring, it is necessary to investigate the passenger flow in the two stage mentioned above. Dalian Metro Line 2 was officially operational in May 22, 2016. Thus, the investigations of passenger flow by bus and car were carried out from April 6 to 9 before subway operation. The investigations of passenger flow by subway, bus and car were carried out from June 15 to 18 and June 22 to 23 after subway operation. Every kind

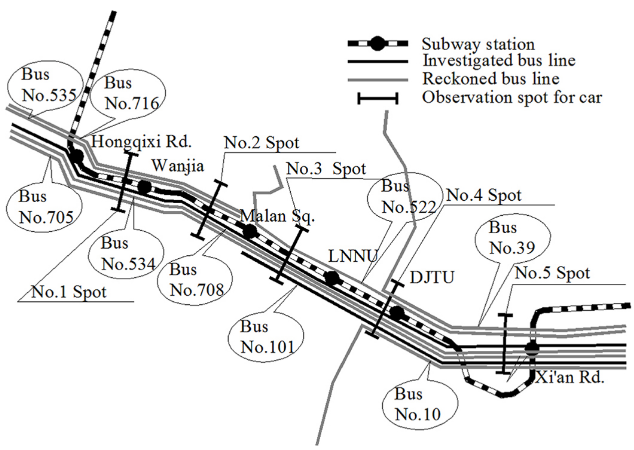

Fig. 1 The traffic construction of investigation segment

of traffic mode was investigated 2 days. The investigation time intervals were selected as 7:00-9:00 in morning peak hour and 16:00-18:00 in evening peak hour.

2.3 The content and method

Because the original passengers partaken by car will transfer to bus and subway as well as the passengers partaken by bus, the characteristic of passenger flow transferring of car should not be ignored. Thus, it is necessary to investigate the passenger flow of bus, car and subway. The investigation methods are mentioned as following.

1. Passenger volume in section of subway
   An investigator is set at each platform of upstream and downstream in every subway stations. In the interval time of every pair of trains, the numbers of passengers at the platform are counted. So, the numbers of passengers who will get on the next train can be acquired. When train arrives at the station, the numbers of passengers who get off the train can also be acquired. In addition, an investigator is set in every train. He should get on the train at the last station of the starting point of investigation segment and count the initial number of passengers in the train. Calculating and analyzing the investigation data, the passenger volume in section of subway can be acquired directly.
2. Passenger volume in section of bus
   Selecting the Bus No. 708 and Bus No. 101 with a large number of passengers, the investigation of passenger volume by bus is carried out. Two investigators are set in every bus. The initial number of passengers in the bus and the numbers of passengers who get on and get off the bus can be counted. According to the data of average departure interval of the bus line, the survey sample can be magnified. So, the passenger volume in section of the bus line can be acquired. In addition, 2 investigators are set at the bus station of Malan Sq. and Dalian Jiaotong University (DJTU for short) respectively. They count the number of passengers who get on the different lines of bus. Thus, the passenger volume in section s of other bus lines can be estimated and calculated according to the ratio of passenger who gets on different bus lines at the stations mentioned above.
3. Passenger volume in section of car
   Using the important intersecting road along the investigated road segment as the dividing point, such as Western Corridor, Fumin Rd., Xinan Rd. and Xishan St., the whole road can be divided into 5 small segments. One observation section of car traffic volume is set in every small segment. The method of video observation is used to record the traffic operation situation at every section. At the same time, 2 investigators are set at here to sampling observe and record the number of passengers in car. In stage of indoor work and data processing, not only the car traffic volume in two directions, but also the average number of passengers in car and sample rate, can be calculated and acquired. According to the above data, the passenger volume in section of car can be magnified and acquired.

3 Contrast and analysis of passengers

3.1 For car

At every section of traffic volume observing, the car traffic volume in two directions is counted as Table 1.

According to the sampling data of the number of passengers by car, the average number of passengers in car before subway operation is 1.94 per car. The number after subway operation is 1.86 per car. Using these average numbers of passengers in car and data in Table 1, the numbers of passengers who select car mode to travel of every section before and after subway operation can be calculated, as Fig. 2 shows.

From Fig. 2, after subway operation, the numbers of passengers by car at every section of observing are less than that before subway operation to some extent. Because the

Table 1 The bidirectional volume of every section at perk hour (pcu)

Observation Spot	Before subway operation				After subway operation			
	April 6th		April 7th		June 15th		June 16th	
	Morning	Evening	Morning	Evening	Morning	Evening	Morning	Evening
No.1 spot	1908	1578	1746	1609	1881	1605	1708	1547
No.2 spot	2152	1838	1958	1766	2105	1715	1849	1795
No.3 spot	2527	2270	2482	2350	2208	2084	2364	2185
No.4 spot	3241	2864	3174	2969	2849	2748	2898	2592
No.5 spot	3296	2985	3250	3027	2982	2709	3067	2866

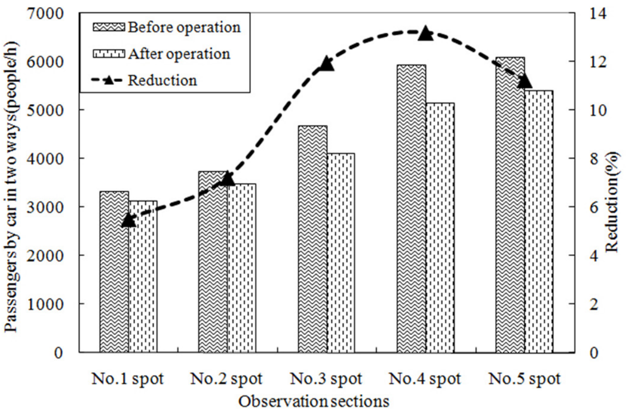

Fig. 2 Passenger volume by car before and after subway operation

No. 1 and No. 2 section are in urban periphery area, theirs proportion of decrease is small. However, the proportions of decrease in other 3 sections are more than 10 %. So, this reduction of the amount of passengers by car is the passenger volume transferring from car to subway and bus after subway operation.

3.2 For bus

According to the initial number of passengers in the bus and the number of passengers who get on and off bus at every station of Bus No. 708 and No. 101 before and after subway operation respectively, the average number of passengers in the bus between every pair of bus stations can be calculated. Combining with the average departure intervals of the two bus lines at peak hour, which is 8 min per vehicle for Bus No. 708 and 6 min per vehicle for Bus No. 101, the passenger volume in section in two directions of each bus line at peak hour can be calculated. The analysis results are shown in Fig. 3.

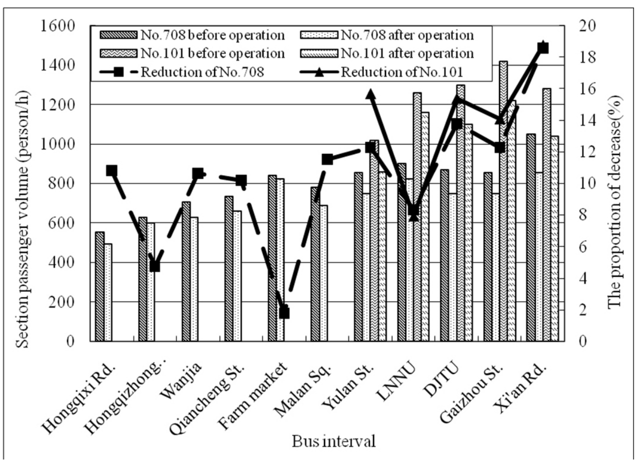

Fig. 3 Passenger volume by No. 708 and No. 101 bus before and after subway operation

From Fig. 3, both the passenger volumes in sections in two directions of the 2 bus lines after subway operation are less than the value before operation in different extent. For the decreasing proportion of passenger volume, the value of the bus interval including subway station is higher than others. This reduction should be the passenger volume transferring from bus to subway or car.

3.3 For subway

According to the investigation data of subway passenger volume and combining with the average arriving interval which is 10 min, the passenger volume in section in two directions of subway at peak hour can be acquired, as Table 2 shows. These passengers should include the passengers transferred from car and bus and the passengers induced by subway itself.

4 Logit model for traffic mode selection

4.1 Trinomial Logit model after subway operation

The Logit model is a disaggregate model, which is constructed based on the theory of random utility. Using this theory, the traffic mode selecting behavior of passenger can be explained. According to this theory, the passenger will select the travel scheme with maximum utility among the several given traffic modes. Based on the theory of random utility, the utility function U_i of a certain traffic mode is composed of the fixed term V_i and the random term ε_i. They follow the linear relationship, as Eq. (1) shows, according to the study of Koryagin and Dekina (2014) and Joseph et al. (2017). The i means a certain traffic mode among the car, bus or subway.

$$U_i = V_i + \varepsilon_i,\quad i = Car \text{ or } Bus \text{ or } Sub \tag{1}$$

Table 2 The passenger volume of every section for the subway at peak hour

Interval	Morning/ people·h^{-1}	Evening/ people·h^{-1}	Arriving interval/min	Passengers/ people·h^{-1}
Hongqixi Rd.-Wanjia	104	66		1698
Wanjia-Malan Sq.	138	104		2424
Malan Sq.-LNNU	214	149	6	3633
LNNU-DJTU	231	189		4203
DJTU-Xi'an Rd.	241	234		4755

LNNU-Liaoning Normal University

Assuming the random terms ε_i of utility function obeying double exponential distribution with the same parameters, the trinomial Logit model after subway operation can be derived, as Eq. (2) to Eq. (4) show.

$$P_{Car} = \frac{\exp V_{Car}}{\exp V_{Car} + \exp V_{Bus} + \exp V_{Sub}} \tag{2}$$

$$P_{Bus} = \frac{\exp V_{Bus}}{\exp V_{Car} + \exp V_{Bus} + \exp V_{Sub}} \tag{3}$$

$$P_{Sub} = 1 - P_{Car} - P_{Bus} \tag{4}$$

where, P_{Car}, P_{Bus} and P_{Sub} are the residents selecting probability of car, bus and subway respectively after subway operation. They also can be regards as the travelling proportion of the corresponding traffic mode above selected by residents.

4.2 Binomial Logit model before subway operation

Before subway operation, the main travelling mode of residents only includes car and bus. So, there are only two selection terms in the Logit model. Therefore, also based on the theory of random utility, the selection model of travelling mode at this stage should be a binomial Logit model, as Eq. (5) and Eq. (6) show.

$$P'_{Car} = \frac{\exp V'_{Car}}{\exp V'_{Car} + \exp V'_{Bus}} \tag{5}$$

$$P'_{Bus} = 1 - P'_{Car} \tag{6}$$

4.3 The calibration method

Taking the trinomial Logit model as an example, the calibration method of its parameters is derived. Combining the Eq. (2), Eq. (3) and Eq. (4), the Eq. (7) and Eq. (8) can be solved.

$$V_{Car} - V_{Sub} = \ln \frac{P_{Car}}{1 - P_{Car} - P_{Bus}} \tag{7}$$

$$V_{Bus} - V_{Sub} = \ln \frac{P_{Bus}}{1 - P_{Car} - P_{Bus}} \tag{8}$$

Thus, which kind of traffic mode is selected by passengers for travelling should be determined by the difference between the fixed term in utility functions. This difference should be related to the time saving F (min) and the cost saving C (CNY) of a certain traffic mode relative to subway. Furthermore, the relationship between them should be linear. So, the relationship models can be assumed as Eq. (9) and Eq. (10).

$$\ln \frac{P_{Car}}{1 - P_{Car} - P_{Bus}} = \alpha_1 F_1 + \beta_1 C_1 + \gamma_1 \tag{9}$$

$$\ln \frac{P_{Bus}}{1 - P_{Car} - P_{Bus}} = \alpha_2 F_2 + \beta_2 C_2 + \gamma_2 \tag{10}$$

where, F_i (min) and C_i (CNY) are saving time and cost of selecting car mode and bus mode for travelling related to subway mode, i = 1 or 2. The α_i, β_i and γ_i are the model parameter needed to be calibrated.

The calibration method and applying process of the model parameters is mentioned as follows:

1. According to the investigation data, the travelling proportions of different traffic modes that are P_{Car} and P_{Bus} in every interval can be calculated.
2. The saving time F_i and saving cost C_i in every interval should be measured and calculated.
3. Using the method of multiple linear regression, the parameters of α_i, β_i and γ_i can be calculated and calibrated.
4. Applying the calibrated model into actuality, the passenger selecting probability of car, bus and subway of other travelling routes in the same area can be calculated.

4.4 Prediction

For prediction, according to the data of investigation, the present total passenger volumes of 3 modes of every section should be calculated first. Second, based on the average growth rate per annum, which can be predicted by the traffic data of past years or estimated by the economic development indicators, the total travelling passenger volumes of future year of every section can be calculated. Third, the model variables of F_i and C_i in future year should be re-estimated. Fourth, according to the calibrated Logit model of Eq. (9) and Eq. (10) in which the parameters of α_i, β_i and γ_i are calibrated by investigation data, the travelling probabilities by car and bus of every section can be calculated. At last, the passenger volume of every kind of traffic mode can be acquired.

5 Adjustment method of bus lines

5.1 Bus line migration

In order to ensure that the service quality of the other lines does not change a lot compared with the service quality before subway operation, after the migration of one line, the variety of passenger volume of the bus should be considered firstly. The D value is defined in Eq. (11).

$$D = \min\left|Q'_{Bi} - \left(Q' \cdot P'_{Bus} - Q \cdot P_{Bus}\right)\right| \quad (11)$$

where, Q'_{Bi} (people/h) is the average volume of passengers of the No. i bus line before subway operation. Q' and Q (people/h) is the total passenger volume before and after subway operation respectively. Thus, the D (people/h) means the minimum difference of passenger flow after the migration of a certain line of bus.

If the ratio of D to the passenger volume undertaken by the migrated bus line is less than N%, where the N is the number of the bus lines remained, it means that the variety of passenger volume undertaken by the bus lines remained is not large. Thus, the service quality of the bus lines remained is also consistent with that before subway operation.

5.2 Adjustment of departing time interval

If the D value does not meet the condition above, the average departing time interval of the i bus line should be adjusted to ensure the operational efficiency and service quality before subway operation. The average departing time interval of the No. i bus line after subway operation can be calculated by Eq. (12).

$$T_i = T'_i \cdot \frac{Q' \cdot P'_{Bus}}{Q \cdot P_{Bus}} \quad (12)$$

where, the T'_i and T_i (min) are the average departing time interval of the No. i bus line before and after subway operation.

5.3 Analysis of operational efficiency

Using the average number K of passengers in bus per hour, the overall operational efficiency of the bus lines remained can be evaluated, as Eq. (13) shows.

$$K = \frac{Q \cdot P_{Bus}}{\sum_{i=1}^{N} \delta_i \frac{60}{T_i}} \quad (13)$$

where, the δ_i is the conversion coefficient of vehicle type, 1 for common bus and 2 for double-layer or articulated bus. According to Eq. (13), the K value is higher means the average number of passengers in every bus per hour is more, and the overall operational efficiency of bus lines is higher correspondingly. However, if the K value is too large, it means the passengers in bus are crowded. The comfort of passenger will be affected.

6 Case study and discussion

6.1 Calibration of the Logit model

Using the investigation results of passenger volumes of car and bus before subway operation, the binomial Logit model before subway operation can be calibrated. The calculation parameters are listed in Table 3. In Table 3, the saving time and saving cost mean that of travelling by car relative to by bus in the same travelling interval. P'_{Car} is calculated and acquired according to the investigation data.

According to the data in Table 3 and using binary linear regression, the regression parameters of the binomial Logit model before subway operation can be acquired. They are $\alpha = 2.394$, $\beta = 2.013$ and $\gamma = -6.46$. Thus, the selection probabilities of passenger travelling by car and bus before subway operation can be calculated according to Eq. (14).

$$\begin{cases} P_{Car} = \dfrac{1}{1 + \exp\left(-2.394F - 2.013C + 6.46\right)} \\ P_{Bus} = 1 - P_{Car} \end{cases} \quad (14)$$

Using the investigation data of passenger volumes of car, bus and subway after subway operation and according to the method above, the trinomial Logit model after subway operation can also be calibrated. The regression calculation parameters are listed in Table 4.

According to the data in Table 4 and using twice binary linear regression, the regression parameters of the trinomial Logit model after subway operation can also be acquired. They are $\alpha_1 = -0.171$, $\beta_1 = 0.071$, $\gamma_1 = 0.733$, $\alpha_2 = -0.231$, $\beta_2 = 0$ and $\gamma_2 = 0.283$. Therefore, the selection probabilities of car, bus and subway after subway operation can be calculated by solving the following system of two element equations, as Eq. (15) shows.

$$\begin{cases} \dfrac{P_{Car}}{1 - P_{Car} - P_{Bus}} = \exp\left(-0.171F_1 + 0.071C_1 + 0.733\right) \\ \dfrac{P_{Bus}}{1 - P_{Car} - P_{Bus}} = \exp\left(-0.231F_2 + 0.283\right) \end{cases} \quad (15)$$

6.2 Model verification

In order to verify the reliability of the model, the model calculating value and the actual investigating value of the travelling proportion by car and bus before and after subway operation in every travelling interval and

Table 3 Regression data for the binomial Logit model

Travelling intervals	Saving time F/min	Saving cost C/CNY	P'_{Car} /%	$\ln \frac{P'_{Car}}{1-P'_{Car}}$
Hongqixi Rd.-Wanjia	3.6	−1	53.9	0.1452
Wanjia-Malan Sq.	4.4	−2	52.2	0.0559
Malan Sq.-LNNU	3.9	−1.4	51.3	0.0581
LNNU-DJTU	4.3	−1.8	54.6	0.2007
DJTU-Xi'an Rd.	4.2	−1.9	44.1	−0.236

Table 4 Regression data for the trinomial Logit model

Travelling intervals	P_{Car} /%	P_{Bus} /%	For car and subway			For bus and subway		
			Saving time F_1/min	Saving cost C_1/CNY	$\ln \frac{P_{Car}}{1-P_{Car}-P_{Bus}}$	Saving time F_2/min	Saving cost C_2/CNY	$\ln \frac{P_{Bus}}{1-P_{Car}-P_{Bus}}$
Hongqixi Rd.-Wanjia	42.1	35.1	1.5	1.9	0.6145	−0.6	−3	0.4322
Wanjia-Malan Sq.	37.8	35.8	2.6	1	0.3585	−0.1	−3	0.3060
Malan Sq.-LNNU	34.4	35.2	4.3	1.6	0.1253	0.6	−3	0.1468
LNNU-DJTU	37.9	31.2	3.9	2	0.2017	1.2	−3	0.0080
DJTU-Xi'an Rd.	32.4	39.1	4.1	1.4	0.1262	−0.2	−3	0.3140

the whole segment are compared with each other. The calculation results of data are shown in Fig. 4.

From Fig. 4, before subway operation, the travelling proportion of car distributes in the interval of 45 % to 55 %. The travelling proportion of bus equals to 1 minus this value. After subway operation, both the travelling proportion of car and bus reduces. This figure also indicates that the difference between the calculation results of the traffic mode selection Logit model before and after subway operation and the actual data investigated is small.

6.3 Adjustment of bus lines

According to the passenger data of investigation, the total volumes of passengers in sections before and after subway operation are Q' = 8355 people/h and Q = 9211 people/h respectively. Using the binomial and trinomial Logit models, the calculated travelling proportions of bus before and after subway operation are P'_{Bus} = 49.3 % and P_{Bus} = 39.6 %. The average volumes of passengers in sections of every bus line per hour Q'_{Bi} before operation and the calculation parameters of adjustment for bus lines are listed in Table 5. In Table 5, $X_i = \left|Q'_{Bi} - \left(Q' \cdot P'_{Bus} - Q \cdot P_{Bus}\right)\right|$.

From Table 5, in the 9 bus lines before subway operation, the X_i value of Bus No. 705 is lest. The ratio of the X_i to the passenger volume in section of this bus line before operation is only 3.8 %. It means that the bus passenger demand volume after subway operation can be undertaken completely by the bus lines remained except Bus No. 705. In addition, the service quality of bus system will not be significantly decreased compared with that before subway operation. Thus, the Bus No. 705 should be removed out of this area.

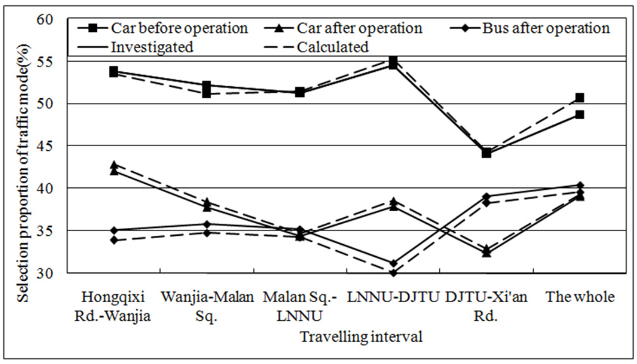

Fig. 4 The comparison of model result and investigation data

Table 5 The Parameter for Bus Line Adjustment

Bus Line	Q'_{Bi} /people·h^{-1}	T'_i /min	X_i /people·h^{-1}	X_i/ Q'_{Bi} /%
No. 708	531	8	60	11.2
No. 101	983	8	512	52.0
No. 705	490	8	19	3.8
No. 534	199	20	273	136.9
No. 535	188	20	284	150.8
No. 716	218	15	254	116.3
No. 39	561	8	90	16.0
No. 10	830	6	359	43.2
No. 522	342	12	130	37.9

6.4 Prediction for 2025

With the growth of total passenger volume in future, the operation condition of every traffic mode could be varied. We assume that the departure interval of subway is reduced by 1 minutes. The ticket price of every bus line is increased by 1 CNY. Thus, the model variables of F_i and C_i in future year should be re-estimated as Table 6 shows. The average growth rate per annum of passenger volume is assumed as 4 %. According to the total travelling passenger volumes at present of every section, the predicted passenger volumes in 2025 can be acquired. By the calibrated Logit model that is Eq. (15), not only the travelling probabilities by car, bus and subway can be calculated, but also the travelling passenger volumes of this 3 modes, as Table 6 shows. In Table 6, the Q_{Car} and Q_{Bus} mean passenger volume by the mode of car and bus.

Table 6 Calculation of prediction passenger volume in 2025

Travelling intervals	Total volume at 2016/ People·h^{-1}	Total volume in 2025/ People·h^{-1}	For car and subway		For bus and subway		2025			
			F_1/ min	C_1/ CNY	F_2/ min	C_2/ CNY	P_{Car} /%	P_{Bus} /%	Q_{Car}/ People·h^{-1}	Q_{Bus}/ People·h^{-1}
Hongqixi Rd.-Wanjia	7446	10597	2.5	0.9	0.4	−3	39.6	33.1	4196	3508
Wanjia-Malan Sq.	9182	13069	3.6	0	0.9	−3	35.1	33.7	4587	4404
Malan Sq.-LNNU	11951	17010	5.3	0.6	1.6	−3	31.4	32.8	5341	5579
LNNU-DJTU	13603	19361	4.9	1	2.2	−3	35.0	28.9	6776	5595
DJTU-Xi'an Rd.	16683	23745	5.1	0.4	0.8	−3	29.9	36.8	7100	8738

For adjustment of bus lines, analogously, the total average volumes of passengers in sections in 2025 is Q = 16756 people/h. The calculated average travelling proportions of bus in 2025 is P_{Bus} = 33.2 %. Thus, the calculation parameters of adjustment for bus lines in 2025 are listed in Table 7.

According to the adjustment principle mentioned above, because the X_i value of Bus No. 535 is lest, this line should be removed out in this area. However, because the X_i/Q'_{Bi} values of all bus lines are so large, the average departing time intervals T_i of all bus line should be adjusted after migration, according to Eq. (12).

6.5 Discussion of operational efficiency

For the same year of subway operation, using the data in Table 5, the total operation efficiencies of bus system before and after subway operation can also be analyzed. Because all of the vehicles of Bus No. 101 are articulated type bus, its conversion coefficient of vehicle type is 2. The calculated K value before subway operation is 65.9 people/vehicle. However, after subway operation, if no adjustment scheme of bus lines is adopted, the K value is 58.4 people/vehicle. According to the analysis result of this case, if the Bus No. 705 is removed out of this area, there are only 8 bus lines serve for the area along subway. Thus, the K value will be 66.3 people/vehicle. Therefore, this adjustment method of bus lines can improve 13.5 % of the operational efficiency of bus system, under the condition of keeping the service quality of bus unchanged in generally.

Table 7 The Parameter for Bus Line Adjustment in 2025

Bus Line	Q'_{Bi} /people·h^{-1}	T'_i /min	X_i /people·h^{-1}	X_i/Q'_{Bi} /%	T_i /min
No. 708	531	8	1975	371.9	6
No. 101	983	8	2427	246.9	6
No. 705	490	8	1934	394.7	6
No. 534	199	20	1643	825.6	15
No. 535	188	20	1632	868.1	—
No. 716	218	15	1662	762.4	11
No. 39	561	8	2005	357.4	6
No. 10	830	6	2274	274.0	4.5
No. 522	342	12	1786	522.2	9

For 2025, if only adjusting the average departing time intervals of all bus line without remove any line, the K value is 65.9 people/vehicle. It is the same as that of before subway operation. If both the strategies of adjusting departing time interval and removing Bus No. 535 are adopted simultaneously, the K value will be 69.2 people/vehicle. Thus, the operational efficiency of bus system can be improved, as well as the congestion level will not be increased a lot.

7 Conclusions

1. After subway operation, the original passenger volumes undertaken by car and bus along subway line will transfer to subway to different extents. The passenger volume partaking rates of every traffic mode can be calculated and solved by the Logit model for traffic mode selection.
2. The adjustment method of bus lines along subway can improve the operational efficiency of bus system, under the condition of maintaining the service quality of bus unchanged after subway operation in generally. The improvement range can be determined by the analysis of bus operational efficiency. This method is also applicable for the future state by passenger volume prediction.
3. The Logit model for traffic mode selection can be applied, only if its parameters are calibrated according to the actual investigation data of passenger volume. The difference between the calculated value of the Logit model and the investigated value is small.

In this research, the passenger investigation was carried out shortly after the Metro Line 2 operated. The passenger flow of subway was in the period of germination. So, the passenger volumes which transfer from car and bus before operation to subway are less as well as the total passenger volume partaken by subway. This problem should be further discussed in further research.

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