Research on Optimal Diversion of Urban Road Traffic in Luoyang under Subway Construction

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Abstract: The construction of urban rail transit affects the road traffic and interferes with the normal traffic flow. Therefore, traffic diversion must be adopted to eliminate the impact of rail transit construction. Based on Wardrop user's equilibrium principle, in this paper, we use MTC curve to establish a congestion speed model according to the characteristics of large traffic volume and high road network density in the city. Taking Luoyang Rail Transit Line 2 as an example, two common diversion schemes and models are given, namely, two schemes of completely closing and closing part of the road sections. Based on the principle of the shortest total travel time after diversion, the traffic distribution of the two routes is calculated under the second scheme, so as to achieve reasonable optimization.

1. Introduction

According to official statistics from the statistics bureau, by the end of September 2018, there were 322 million motor vehicles in China. 72.98% of which were cars. In Luoyang, the "Millennium Imperial Capital, Peony City," the population was 6,823,000 in 2017 and 7,101,000 in 2018 with an increase of 4.074% over last year. The huge population and traffic volume as well as the increasingly serious traffic jam have pushed forward the implementation of rail transit. The subway construction has restricted the road traffic conditions and interfered with the normal traffic flow, so traffic diversion is of great significance. Traffic diversion organizations have thus become an important task in subway construction projects.

Fan Liqiang [1] evaluated the road traffic during the construction period of rail transit, and established the impact model of construction on road traffic capacity. Cao Jianping[2] analyzed the influencing factors of traffic capacity in the road maintenance operation area; Yang Qingxiang[3] carried out microscopic simulation analysis on several important influencing factors by using Vissim simulation software, and calculated the traffic capacity during road construction. Ru Honglei [4]used analysis-calibration method to study two important influencing factors and calculated the recommended values. Based on the advanced congestion speed model at home and abroad and Wardrop user's equilibrium principle, in this paper, we present two common traffic diversion schemes and models during the construction period of rail transit. Taking Luoyang Urban Rail Transit Line 2 as an example, the traffic distribution of the two routes under the second scheme is calculated to achieve reasonable optimization.

2. Model Construction

Considering the relationship between congestion speed and free flow speed, road capacity and traffic volume, the experts put forward a more advanced congestion speed model:

$$v = v_f \Big/ \left[1 + 0.2 \times \left(Q/C\right)^{10}\right] \tag{1}$$

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where V is the speed of traffic in a traffic jam, V_f represents free flow velocity that is not affected by upstream or downstream, Q stands for traffic volume, C indicates the capacity of a road.

2.1 Road Running Model before Rail Transit Construction.

Suppose the layout of the urban road network is shown in Fig. 1.

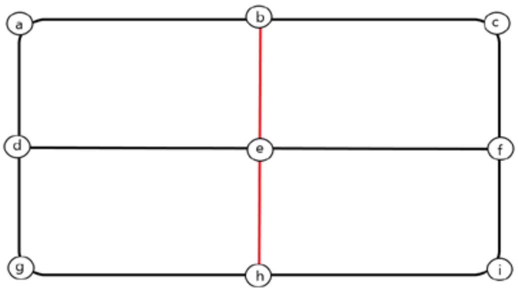

Fig. 1 Urban road network layout

Normally, travelers will choose route b→e→h if he go from b to h. For this lane, assuming the distance of the route is S, then the total running time of the section is

$$T = S/V = S \times \left[1 + 0.2 \times \left(Q/C\right)^{10}\right] \Big/ V_f \tag{2}$$

where $T_f = S/V_f$ the running time under free flow.

For n lanes, if the traffic flow is evenly distributed in each lane and the traffic flow on each lane is random, the total running time from b to h can be obtained as

$$T_{总} = \sum_{i=1}^{n} T_i = \sum_{i=1}^{n} T_{f_i} \left[1 + 0.2 \left(Q_i/C_i\right)^{10}\right] \tag{3}$$

where T_i represents the running time of vehicles on the lane i, T_{f_i} represents the running time of free flow on the lane i, Q_i represents the traffic volume on the lane i and C_i represents the road capacity of the lane i.

2.2 Construction Characteristics of Rail Transit.

Huge population, traffic flow and increasingly serious traffic congestion have promoted the implementation of rail transit. After the construction of Luoyang urban rail transit, it will provide fast, safe, environmentally friendly and large capacity modern rail transit services for passengers.

Rail transit is a huge comprehensive and complex system, and its construction features are as follows: 1) large-scale construction and large project investment; 2) the location of subway stations generally chooses places with large traffic, high population density and high activity; 3) long construction cycle, and the construction cycle of single line takes 4-5 years. Under such characteristics, it is necessary to divert rail transit.

2.3 Model of Traffic Time.

As shown in Fig. 1, according to the characteristics of rail transit construction in Figure 2.2.1, metro stations are generally located at the central point e. In the construction of subway entrance, there are two kinds of construction partition schemes: one is to close all the lanes leading to b d f h; the other is to close part of the lanes, that is, some lanes allow vehicles to pass through, so as to divert.

Modeling Principle: Whatever scheme is adopted to divert traffic, the ultimate goal is to minimize the total running time of all vehicles after diversion. The time is transformed into the time when the last car leaves the exit.

Therefore, when the rail transit is built, the total travel time can be modeled:

$$T = \min T_{总} \tag{4}$$

2.4 The Construction of Road Traffic Time Model for Rail Transit and the Optimization

Analysis under Two Scenarios.

When adopting the scheme-optimized diversion, it is still considered that the traveler from b→n and the number of lanes under normal conditions is n, then the b→e→h road cannot pass, and the number of lanes becomes $(n-1)$.

Assuming that the construction of the subway in the jth lane is closed, then

$$T_{总} = \sum_{i=1, i \neq j}^{n} T_{\mathrm{i}} = \sum_{i=1, i \neq j}^{n} T_{f_i} \left[1 + 0.2 \left(Q_i^{'} / C_i \right)^{10} \right] \tag{5}$$

Which indicates that the traffic volume of each road after the traffic of the original lane is allocated after the lane is closed,

$$Q_i^{'} = Q_i + \Delta Q_i \tag{6}$$

among them, $\sum_{i=1, i \neq j}^{n} \Delta Q_i = Q_j$.

In particular, the introduction of the Wardrop user equilibrium principle assumes that travellers are trying to minimize their travel costs, that is, to pursue a balance caused by maximizing their own interests. For this problem, when the user balance is realized, for the traveler who travels the same OD (starting point),except for the jth lane, the travel time of the vehicle when traveling on other road sections is equal and less than the jth The driving time of the lanes distributes the traffic volume of the first lane evenly to other lanes.

$$\begin{aligned} & T_i < T_j \\ & T_1 = T_2 = \cdots = T_n, n \neq j \\ & T_j = +\infty \end{aligned} \tag{7}$$

$$T_{总} = \sum_{i=1, i \neq j}^{n} T_{f_i} \times \left[1 + 0.2 \times \left(Q_i^{'} / C_i \right)^{10} \right] = \sum_{i=1, i \neq j}^{n} T_{f_i} \times \left[1 + 0.2 \times \left(\left(Q_i + \Delta Q_i \right) / C_i \right)^{10} \right] \tag{8}$$

When the scheme 2 is used to optimize the diversion, the above-mentioned Wardrop user equalization principle is still satisfied, and the number of lanes also becomes $(n-1)$, but the total time model has changed, taking into account the travel time cost of the lane j.

$$\begin{aligned} T_{总} = \sum_{i=1, i \neq j}^{n} T_{\mathrm{i}} + T_j = \sum_{i=1, i \neq j}^{n} T_{f_i} \left[1 + 0.2 \left(\left(Q_i + \Delta Q_i \right) / C_i \right)^{10} \right] + \\ T_{f_j} \left[1 + 0.2 \left(\left(Q_j + \sum_{i=1, i \neq j}^{n} \Delta Q_j \right) \middle/ C_i \right)^{10} \right] \end{aligned} \tag{9}$$

3. The Empirical Analysis

Through the establishment of the above models, the results of the solution can be timely feedback to each traveler, and the way of radio station or traffic police command can be adopted to enable travelers to have more accurate judgment of route selection, so as to achieve the effect of traffic diversion.

In this paper, we take Luoyang Urban Rail Transit Line 2 as an example. As the "millennium imperial capital, peony city", Luoyang is favored by more and more tourists. Luoyang's total tourism revenue peaked at 114.5 billion yuan in 2018. In addition, the population of Luoyang is also on the rise. At present, the urban population is about 2.6 million, and the registered population is about 7.1 million. The traffic pressure of luoyang is increasing day by day, and the convenience of citizens' travel is greatly reduced. The first phase of luoyang metro construction plan was officially reported to the national development and reform commission in February 2016. The first phase of luoyang metro line 1 is expected to be put into operation in 2021, and the first phase of luoyang metro line 2 is expected to be put into operation in 2022. During this period, the problem of road congestion in luoyang city will only increase. The fast lane in the east half of zhongzhou intersection to kaixuan intersection of jiefang road in luoyang city will be blocked, as shown in figure 2.

Fig. 2 Traffic map of intersection of Zhongzhou road and Jiefang road, Luoyang city

Traffic in the region will be maintained in its current state until December 30, 2020. This paper takes this region as the research object and interprets the distributary benefit of the model in detail. As shown in FIG. 1, A stream of traffic is about to arrive at tanggong road B from point A of jiefang road. Before the road section is closed, it can be reached directly by A straight line from jiefang road. After the road section is closed, two scheme routes are selected from the optimal route. Plan 1: starting point a-zhongzhou middle road -- middle section of cotton mill south road -- tanggong road -- terminal B; Plan 2: starting point a-zhongzhou middle road -- middle section of bayi road -- tanggong road -- terminal B. Take this as the two alternative paths of diversion.

According to international standards, the above highway pavement grade can be divided into secondary roads. The design road width of secondary roads is 16 meters, the design speed is 40km/h-80km/h, and the traffic capacity is 550pcu/h-1600pcu/h.

In this paper, in order to better obtain the diversion optimization model, the design speed of the above secondary highway is taken as 65km/h, and the capacity is taken as 1500pvu/h.

According to the OD data of luoyang residents, the morning peak of luoyang city is from 7 to 8 o 'clock in the morning, and the evening peak is from 5 to 7 o 'clock in the afternoon. Therefore, the total traffic volume passing point A in the long period of the survey, namely from 17 to 18 o 'clock in the afternoon, is 4000pcu/h. According to the principle of equal probability, the traffic volume of 1000pcu/h in each of the four directions leading to point A is 1000pcu/h, so the traffic volume assigned to the two scheme routes is 1000pcu/h, in addition, the passenger flow of 1000pcu/h on the a-b direct route is assigned to the two scheme routes. Fig. 3 shows the distribution of traffic congestion periods in luoyang city.

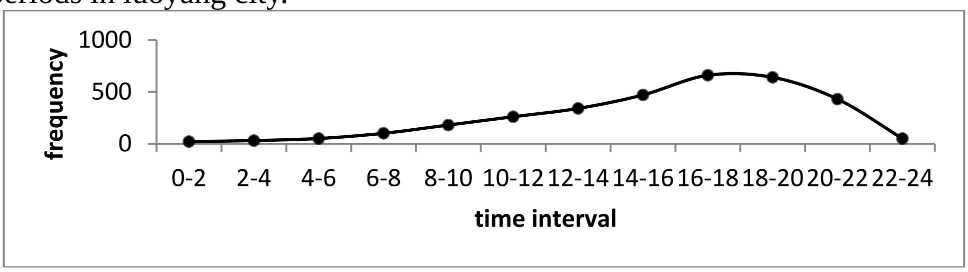

Fig. 3 Road traffic jam time distribution broken line map of Luoyang city

According to the measurement, the total route length of scheme 1 is 1.527km, and that of scheme 2 is 1.238km.

According to the traffic diversion model established in this paper, we can get

$$T_1 = T_{f_1}\left\{1+0.2\times\left[\left(Q_1+\Delta Q_1\right)/C_1\right]^{10}\right\}, \tag{10}$$

$$T_2 = T_{f_2}\left\{1+0.2\times\left[\left(Q_2+\Delta Q_2\right)/C_2\right]^{10}\right\} \tag{11}$$

$$T_1 = T_2 \tag{12}$$

$$\Delta Q_1 + \Delta Q_2 = 1000 \tag{13}$$

Let $x = \Delta Q_1$, then we know

$$16.2+16.92\left[\left(1000+x\right)/1500\right]^{10} = 13.68\left[\left(2000-x\right)/1500\right]^{10}$$

With the help of MATLAB, we have

$$x = solve\left('16.2\times1500^{10}+16.92\times\left(1000+x\right)^{10} = 13.68\times\left(2000-x\right)^{10}','x'\right).$$

Then, it follows that $\Delta Q_1 = x = 406, \Delta Q_2 = 594$.

Therefore, the traffic volume of 406pcu/h should be allocated for the first route and 594pcu/h for the second route, which satisfies wardrop user's equilibrium principle and can achieve reasonable diversion.

4. Conclusion

The construction of urban rail transit is of great significance in alleviating urban road traffic. However, the obstacle caused by subway construction to the ground road traffic is an urgent problem to be solved. In this paper, based on the wardrop user's equilibrium principle, according to the characteristics of urban traffic, the congestion speed model is established by using the MTC curve. Taking Luoyang Rail Transit Line 2 as an example, two common diversion scheme and model are given. Based on the principle of the shortest total travel time after diversion, the traffic distribution of the two routes under the second scheme is calculated, so as to achieve a reasonable optimization. The model satisfies the principle of minimum total travel time and maximum benefit to the greatest extent, and is applicable to subway construction, road construction and sudden road segment events.

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