Study on the Capacity of Urban Road Construction Section under Mixed Traffic Environment

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Abstract. Based on the analysis of the calculation model of the capacity of urban road construction section, a calculation optimization model considering the influence of non-motor vehicle factors on the capacity of construction section is established. Through the recording and calibration of the geometric and traffic parameters of the construction section at the intersection of Huangshan Road and Susong Road in Hefei City, and using PTV-VISSIM10 for modeling and calculation, the calculation model of non-motor vehicle reduction factor is constructed. Finally, the optimization model of the capacity of the construction section is verified by combining with observation data of the morning peak of the urban road construction section under mixed traffic environment. The results show that the relative error between the calculated value of the capacity and the observed value of the construction section under mixed traffic environment is less than 5%. Therefore, it is reasonable to consider the non-motor vehicle reduction factor on the capacity calculation model of the construction section, and make up for the original model to only consider the insufficient factors such as the proportion of the large vehicle, length of work area and speed limit value.

1. Introduction

With the rapid growth of the social economy, urban road infrastructure construction needs to be continuously improved. Due to the need to set up a construction area on the road during construction, it is easy to induce traffic congestion and accidents. Therefore, constructing a reasonable calculation model for the capacity of urban road construction section can lay a theoretical foundation for the formulation of a reasonable traffic organization plan and provide a basis for effective traffic management measures. When calculating the possible capacity of urban road construction section, it is usually based on the basic capacity, and then multiplied by the reduction factors of the various influencing factors under actual road, traffic environment conditions. However, for the determination of the reduction factor, only the factors such as the proportion of large vehicles and the speed limit value are usually considered. It is neglected that mixed traffic is the characteristic of urban road traffic in China, ignoring the influence of non-motor vehicle factors on capacity. For studying the influencing factors of non-motor vehicles, the non-motor vehicle reduction factor method proposed by the American Highway Capacity Manual (HCM2000) is widely used[1]. This method estimates the average occupancy rate of non-motor vehicles that conflict with motor vehicles, the time ratio of the non-motor vehicle occupation is analyzed by the aggregate, and the reduction factor is quantified, but this method is difficult to apply to the road construction section. Many scholars in China have also carried out many studies, mainly by using probability and statistics methods to analyze the measured traffic flow data, then obtain the reduction factor among the influencing factors on capacity[2]. Some
scholars also use simulation technology to build the model method for solving the capacity of urban road construction section[3]. In general, there are still few research results on the non-motor vehicle factors involved in the capacity of urban road construction section at home and abroad.

This paper mainly analyzes the impact of the non-motor vehicle factors on the capacity by investigating the field data of the construction section at the intersection at Huangshan Road and Susong Road, and establishes a calculation model for the calculation of the capacity of the construction section considering the non-motor vehicle factors, and combines the field observation data to verify the optimization model.

2. Traffic investigation and simulation modeling

2.1. Intersection section occupied the road construction area

During the construction of the subway, the road section at the intersection usually adopts occupying-road construction. Generally, the entire affecting area can be divided into four parts: the warning area, the upstream transition area, the construction operation area and the downstream transition area[4], detailed as Figure 1.

As can be seen the warning area is located at the forefront of the construction affecting area. This area reminds the driver to adjust driving state to adapt to the changes in the road environment ahead by setting signs such as construction, deceleration and narrowing of the road. The upstream transition area which guides the driver to take the deceleration into the closed section of the lane. In order to ensure the safe convergence of the traffic flow, the upstream transition area needs to be set to a sufficient length. The construction operation area in the middle is a closed area for normal construction work, the eye-catching road signs should be set up at the side of the area, and the normal traffic of the inner lanes should be ensured by means of channelization or roadblocks due to vehicles in this area can only travel in the same direction. The fourth part of the construction affecting area is called the downstream transition area, the driver usually adopts an accelerated rapid departure from the bottleneck section, and the downstream transition area is used to guide the vehicle out of the construction area to smoothly enter the basic road section.

2.2. Selection of subway construction section and investigation method

Combined with the construction project of Hefei Metro Line 5, the 700 m section between the intersection of Huangshan Road-Jinzhai Road and the intersection of Huangshan Road-Shuguang Road was selected, and the traffic flow data was collected by using aerial photography of the drone and camera, and the morning and evening peak traffic conditions in the construction area were recorded by video recording. The construction operation area is located at the intersection of Huangshan Road and Susong Road. The direction of Susong Road is fully enclosed, and the direction of Huangshan Road is separated by central guardrail, the current status of the road is 3.5 m, and take one-way 4 lanes to close 2 lanes for construction. The general situation is shown in Figure 2.

The field survey method is used to investigate the geometric parameters of the subway construction area, including the number of lanes, the width of the lane and the type and length of the enclosure in the construction area. Investigating the speed and traffic volume of the construction area by using camera monitoring and aerial photography of drones. Firstly, two video cameras were set up in front of the warning area and the construction operation area, then the information such as the type, quantity,
driving time and departure time of all vehicles passing through the construction area were recorded by manual statistical method. Finally, the video processing software SIMI is used to extract the aerial video images, and the basic data such as the average headway distance and the speed of vehicles are obtained. Camera point locations as Figure 3.

![Figure 2. Actual drawing of subway occupation construction area.](image1)

![Figure 3. Schematic diagram of traffic volume collection and camera point locations.](image2)

### 2.3. Investigation results

Table 1 shows the traffic volume of motor vehicles and non-motor vehicles at the evening peak of the intersection of Huangshan Road and Susong Road. Most of the vehicles are buses, cars and non-motor vehicles, and other vehicles uniformly classified as standard car. From the road centerline, the motor vehicle average speed in the inner lane is 24.1 km/h, the motor vehicle average speed in the outer lane is 22.6 km/h, and the non-motor vehicle average speed is 16.8 km/h.

| Time               | Inner lane traffic volume | Outer lane traffic volume |
|--------------------|---------------------------|---------------------------|
|                    | Car (veh) | Bus (veh) | Non-motor vehicle (beu) | Car (veh) | Bus (veh) | Non-motor vehicle (beu) |
| 17:30-17:40        | 169       | 6         | 5                        | 139       | 2         | 9                        |
| 17:40-17:50        | 172       | 4         | 3                        | 123       | 0         | 11                       |
| 17:50-18:00        | 153       | 5         | 1                        | 155       | 1         | 8                        |
| 18:00-18:10        | 167       | 6         | 4                        | 140       | 2         | 11                       |
| 18:10-18:20        | 161       | 4         | 2                        | 124       | 0         | 13                       |
| 18:20-18:30        | 186       | 5         | 2                        | 147       | 3         | 9                        |

### 2.4. Simulation modeling and parameter calibration

Through the collection and analysis of the field data, in this study, since the designed vehicle speed in the PTV-VISSIM10 simulation model is 62 km/h, the test vehicle speed is set to 22-62 km/h, and the deceleration zone speed is set to 20-40 km/h, the non-motor vehicle speed is set to 12-30 km/h, and the length of the construction operation area is set to 200 m.

In the simulation modeling of the road section construction area, the simulation model of PTV-VISSIM10 road section is constructed by defining the vehicle composition, vehicle flow input, setting vehicle speed distribution, path selection, deceleration area, etc. As shown in Figure 4.

![Figure 4. Simulation model of construction section.](image3)
3. Calculation optimization model for the capacity of construction section

3.1. Calculation model of possible capacity of construction section

The possible capacity of the urban road construction section is the maximum number of standard vehicles passing through a uniform section or a cross section under the actual road, traffic environment conditions. On the basis of considering the theoretical capacity, multiplying by the different reduction factors. Define the reduction factors of capacity: the number of lanes reduction factor \( f_1 \); lane width reduction factor \( f_w \); intersection reduction factor \( f_c \); speed limiting factor \( f_v \); large vehicle proportional reduction factor \( f_{HV} \); operation area length reduction factor \( f_l \); comprehensive reduction factor with influences such as railroad crossings \( f_z \).

Considering all the above-mentioned influencing factors, the possible capacity of urban road construction section is:

\[
C_a = C_0 \times f_1 \times f_w \times f_c \times f_v \times f_{HV} \times f_l \times f_z
\]

(1)

Among them due to \( f_l \) takes the value 1, \( f_z \) is more complicated and usually be ignored, so equation 1 can be simplified as:

\[
C_a = C_0 \times f_1 \times f_w \times f_c \times f_v \times f_{HV}
\]

(2)

In the formula: \( C_0 \) for the theoretical capacity of a lane, veh/h. According to the Urban Road Engineering Design Specification (CJJ37-2012)[5], the theoretical capacity of a single lane can be taken as follows.

| \( v \) (km/h) | 60 | 50 | 40 | 30 | 20 |
|---------------|----|----|----|----|----|
| \( C_0 \) (veh/h) | 1730 | 1690 | 1640 | 1550 | 1380 |

Table 2. Theoretical capacity of a single lane.

It can be found from equations 1 and 2 that the original calculation model does not consider the influence of non-motor vehicle factors on the capacity of the construction section under mixed traffic environment. Therefore, it is particularly important to propose a optimization model for the calculation of the capacity considering non-motor vehicle factors.

3.2. Construction of non-motor vehicle reduction factor calculation model

The influence of non-motor vehicles is related to the presence or absence of separation belts between motor vehicle lanes and non-motor vehicle lanes. If there is no separation between the two types of lanes, especially in urban road construction section under mixed traffic conditions, the incompatibility of non-motor vehicles has certain interference to the passage of motor vehicles, forcing the drivers be vigilant and slow down. It is mainly related to the characteristics of non-motor vehicles, such as small volume, low speed, no fixed driving track during riding and so on. The calculation model considering the influence of non-motor vehicle factors on the capacity mainly refers to the relationship between the non-motor vehicle flow and the possible capacity of motor vehicle. By establishing a simulation model, using the non-motor vehicle flow and motor vehicle capacity reduction factor for regression analysis, then the non-motor vehicle reduction factor calculation model is constructed.

Through the analysis of the simulation data, with the increase of non-motor vehicle inflow, the actual capacity of the inner lane is basically unchanged, while the outer lane capacity is gradually reduced. When the hour flow rate of non-motor vehicle is 150-300, the drop is especially noticeable, as shown in Figure 5. On the other hand, with the increase of the non-motor vehicle inflow, the inner lane traffic speed is maintained at about 22 km/h, while the outer lane traffic speed is gradually reduced, when the hour flow rate of non-motor vehicle is more than 100, the average speed of the lane is already less than 20 km/h, as shown in Figure 6. Finally, as seen from Figure 7. With the increase of non-motor vehicle inflow, the average delay of the inner lane is maintained at about 23%, especially
when the non-motor vehicle hourly inward volume is more than 150, the increase in outer lane delay is particularly obvious.

![Figure 5. Impact of non-motor vehicle inflow on motor vehicle capacity.](image1)

![Figure 6. Impact of non-motor vehicle inflow on speed.](image2)

![Figure 7. Impact of non-motor vehicle inflow on delay.](image3)

![Figure 8. Scatter fitting diagram of non-motor vehicles reduction factor.](image4)

It can be seen that the non-motor vehicle inflow has little influence on the motor vehicle capacity, speed and delay on the inner lane. So the influence of non-motor vehicle inflow on the outer lane is mainly considered. By determining the non-motor vehicle inflow $q$ as an independent variable, the outer lane capacity reduction factor $f_b$ as the dependent variable, drawing a scatter fitting diagram as shown in Figure 8. Linear and nonlinear regression analysis of non-motor vehicle inflow and reduction factor were carried out by using SPSS (Statistical Product and Service Solutions). The results show that the exponential function has the best fitting effect in nonlinear regression, see Table 3.

| Equation   | Model summary | Parameter estimate |
|------------|---------------|--------------------|
|            | $R^2$  | $F$   | $df_1$ | $df_2$ | Sig. | $a$  | $b$   |
| Linear     | 0.894   | 301.2 | 1      | 48     | 0.71  | 0.941 | -0.001 |
| Nonlinear  | 0.932   | 635.5 | 2      | 47     | 0.00  | 0.997 | -0.002 |

According to the analysis of the simulation data, non-motor vehicle reduction factor calculation model is established:

$$f_b = 0.997e^{-0.002q}$$

(3)
3.3. Construction of calculation optimization model for the capacity of construction section

The calculation optimization model considering the influence of non-motor vehicle factors on the capacity of urban road construction section is as follows:

\[ C_a = C_0 \times f_t \times f_w \times f_c \times f_{HV} \times f_b \]  (4)

According to formula 4, the possible capacity of the construction section is disturbed by various influencing factors, and the following factors usually need to be considered: firstly, the influence of the number of lanes \( f_t \), because the vehicles traveling in the same direction may affect the capacity of the adjacent lanes due to overtaking, parking. Generally, the reduction factor of the first lane from the road centerline is 1.00, the second lane is 0.80-0.89, the third lane is 0.65-0.78[6]; secondly, the influence of the width of the lane. When the width of the lane does not meet the requirements, overtaking and lane changing will be affected during the driving of the vehicle, the standard lane width is usually 3.5 m in urban road design, when the lane width is greater than 3.5 m, the capacity is basically unaffected; but when the lane width is less than 3.5 m, the vehicle's driving speed and the capacity will be significantly reduced, which can be determined by the following formula:

\[ f_w = 50 \times (w_0 - 1.5) \% \]  
\( w_0 \) is the width of the lane[7]; thirdly, the influence of the intersection \( f_c \), especially when the vehicles pass through the small spacing intersection, the actual transit time will increase due to the need to decelerate under the traffic control, which results in a decrease on the capacity of the road section, but when the intersection spacing is greater than 200 m, it can be expressed \( f_c = 1 \); fourthly, the impact of speed limit \( f_v \), it is very necessary to limit the speed of the work area for safety. Fan Wenting uses simulation software VISSIM to analyze different speed limits, taking the speed limit value as the independent variable, the capacity reduction factor as the dependent variable, and the formula \( f_v = -0.0003v^2 + 0.0206v + 0.3937 \) is obtained; finally, the influence of the proportion of large vehicles \( f_{HV} \), large vehicles occupy more space on the road, due to poor maneuverability, weak lane changing ability, which will affect adjacent vehicles easily during driving, Fan Wenting takes the large vehicle ratio \( x \) as the independent variable, the capacity reduction factor \( f_{HV} \) as the dependent variable, and the formula \( f_{HV} = -0.72x + 0.9857 \) is obtained[8].

4. Example verification

This paper takes the calculation of the capacity of the construction section at the intersection of Huangshan Road and Susong Road as an example. According to the investigation of the morning peak traffic flow, the results are shown in Table 4.

| Time       | Inner lane traffic volume | Outer lane traffic volume |
|------------|---------------------------|---------------------------|
|            | Car (veh) | Bus (veh) | Non-motor vehicle (beu) | Car (veh) | Bus (veh) | Non-motor vehicle (beu) |
| 7:30-8:30  | 947       | 39        | 14                      | 708       | 5         | 158                      |

The morning peak observation traffic volume is used to verify the optimization model. According to the data of the above-mentioned evening peak observation data, the average speed of the inner lane of the construction section is 24.1 km/h, the outer lane is 22.6 km/h, so the limit speed of the operation area is 30 km/h, and the reduction factor of each influencing factor of capacity is shown in Table 5.

| Reduction factor | \( f_t \) | \( f_w \) | \( f_c \) | \( f_v \) | \( f_{HV} \) | \( f_b \) |
|-----------------|--------|--------|--------|--------|--------|--------|
| Inner lane      | 1      | 1      | 1      | 0.74   | 0.91   | 0.97   |
| Outer lane      | 0.85   | 1      | 1      | 0.74   | 0.97   | 0.73   |
Finally, the capacity calculation model of the construction section considering the non-motor vehicle factors is used to calculate the possible capacity of the road section. As shown in Table 6.

Table 6. Theoretical calculated value and observed value of construction section capacity.

|                  | Calculated value (veh/h) | Observed value (veh/h) | Relative error (%) |
|------------------|--------------------------|------------------------|--------------------|
| Inner lane       | 1013                     | 1064                   | 4.79               |
| Outer lane       | 691                      | 723                    | 4.43               |
| Sum              | 1704                     | 1787                   | 4.64               |

It can be seen from the above results that the calculated value of the optimization model of the construction section considering the non-motor vehicle factors is very close to the observed value, and the relative errors of both the inner and outer lane are within 5%, the total relative error is 4.64%, so the optimization model of the capacity calculation of urban road construction section considering non-motor vehicle factors is feasible.

5. Conclusion
By analyzing the non-motor vehicle factors affecting the capacity of urban road construction section, the non-motor vehicle reduction factor is introduced to make up for the shortage of typical factors in the original calculation model of the capacity of the construction section. The simulation model is calibrated based on the observation data of the construction section, and the simulation results are used to construct the calculation model of the non-motor vehicle reduction factor, the calculation model of the construction section capacity is optimized. Finally, the optimization model is verified by using the morning peak of the observation data, the results show that the relative error between the calculated value and the observed value is within 5%. Therefore, studying the capacity of the construction section considering the non-motor vehicle factors is reasonable.

Acknowledgments
This work was supported by the National Natural Science Foundation of China [grant No. 51878236].

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