Evaluating the Impact of Road Constructions on Oversaturated Intersections: A Simulated-Based Case Study

Enjian Yao1*, Hao Shen2, Ning Huan2
1 Key Laboratory of Transport Industry of Big Data Application Technologies for Comprehensive Transport, Beijing Jiaotong University, Beijing, 100044, China
2 School of Traffic and Transportation, Beijing Jiaotong University, Beijing, 100044, China
*Corresponding author’s e-mail: enjyao@bjtu.edu.cn

Abstract. During the road construction, the road capacity would be affected by the construction activities. Moreover, unreasonable traffic organization in construction area not only aggravate the decline of road capacity, but also greatly affect the operation of surrounding traffic. Thus, it is necessary to optimize the traffic organization with construction activities, including optimize the signal timing scheme of intersections and analyze the impact of construction area design.

First, taking the construction of Metro Line 6 in Chengdu, China as the studying case, the signal timing is optimized with the minimization of vehicles delay as the optimization objective. Then, a comprehensive sensitivity analysis of the size of working area and the length of transition area is further performed. The results show that the length of construction working area should be set as short as possible, while the transition area has the least impact on traffic operation when its length is set at 50m ~ 60m. Meanwhile, with the increase of the length of the construction area, the intersection with higher green letter ratio would be less sensitive to the changes.

1. Introduction

Since the construction area usually changes the shape of the road and the traffic environment, the traffic situation near the road construction area is very complex. Besides, unreasonable traffic organization also reduce the road traffic efficiency. There are many solutions to alleviate traffic congestion during construction period, among which the method of road expansion is expensive and time-consuming. However, the method of changing the timing of road signal control is more efficient, which is lower cost and more time-saving. Therefore, using signal control method is one of the common methods to manage traffic flow during construction period.

In order to analyze the impact of construction areas on road, scholars have conducted many researches. First construction areas will affect the operation of traffic. Damen [1] analyzed the impact of road micromanagement on capacity and verified that the capacity of the ramp entrance was positively related to the steady flow. After that Fei [2] proposed a meticulous two-lane cellular automaton model and presented a two-lane highway traffic model with a work zone. Wen [3] studied the flow-speed relationship in the confluence area of expressway construction and confluence behaviour of drivers. Xiao [4] simulated of traffic on the road work zone by using VISSIM from the aspects of data investigation, establishment of simulation model and model verification.

Besides construction areas impact on capacity directly, Li [5] proposed a multi-factor-based vehicle capacity modeling method for road construction areas. Then Bhutani [6] and Sun [7] used VISSIM to
study the impact of construction zones on traffic. The results showed that systematic work zone scheduling and traffic management techniques reduce the impacts of construction work zones.

Thus, scholars have given many traffic organization methods to organize traffic in construction area. To evaluate the impact of road construction and maintenance scheme on traffic, Donnelly [8] established a microscopic simulation model and predicted the impact of road closure on traffic patterns and routes. After that, Zhang [9] focused on the traffic organization scheme of intersection construction, and alleviated traffic pressure of intersection by traffic flow guidance, canalization design. In addition, some scholars used simulation to scheme traffic reasonably during construction period.

Although many researches have been carried out, they mainly focus on the traffic capacity and the organization of traffic flow in the construction area. There are less studies on signal control of the construction area, Huang [10] conducted a preliminary study on the signal control of intersections in the construction area. Therefore, optimizing the traffic flow reasonably in the construction area, improving the traffic efficiency, and alleviating the traffic congestion are the main objectives in this paper.

Based on the construction of Chengdu Metro Line 6, this paper analyzes the impact of transition area and working area length on road traffic. By minimizing vehicle delay and considering the construction activities for traffic signal control, we make use of traditional signal control theories and apply the VISSIM tool to adjust the signal timing of intersections in the construction area. Finally, we analyze the performance of traffic optimization scheme during the construction period, from the aspects of average vehicle queuing length, vehicle delay time, average parking time, and parking times.

2. Simulated-based timing method

2.1. Isolated signal control

At present, Webster timing model is a commonly used calculation method in traffic signal control. It is a method to calculate the signal timing with the goal of minimizing the vehicle delay time. The signal timing parameters are as follows.

1) Traffic flow ratio at intersections

The traffic flow ratio of intersection is the sum of the traffic flow ratio of each phase signal critical lane, and the critical lane refers to the lane with the largest traffic volume in each signal phase. The traffic flow ratio $Y$ is defined as

$$ Y = \sum_{i=1}^{n} \max \{ y_i \} $$

$$ y = \frac{q}{s} $$

Where $n$ is the number of phases in a period; $y_i$ is the flow ratio of phase $i$; $q$ is the traffic flow of lane, pcu/h; $s$ is the saturated flow of lane, pcu/h.

2) Total signal loss time

$$ L = nl + AR $$

Where $l$ is the start-up loss time; $n$ is the number of phases of the signal; $A$ is yellow light time in the cycle; $R$ is red time in the cycle.

3) The formula for calculating the optimal cycle

Assuming that there are $n$ signal phases in a cycle, the total vehicle delay at the intersection should be

$$ D = \sum_{i=1}^{n} q_id_i $$

Where $d_i$ is the vehicle delay at the phase $i$; $q_i$ is the vehicle arrival rate for phase $i$.

In order to ensure the minimum vehicle delay at intersections, the optimization problem of cycle length can be summarized as follows.

$$ \min D = \sum_{i=1}^{n} q_id_i $$
\[ C \geq \frac{L}{1 - y} \]  

(6)

By calculating the partial derivative of the cycle, combined with equivalent substitution and approximate calculation, the optimal period calculation formula can be derived as

\[ C_0 = \frac{1.5L + 5}{1 - Y} \]  

(7)

Where \( L \) is the total loss time and \( Y \) is the traffic flow ratio at intersections.

### 2.2. Coordinated signal control

To reduce the parking time of vehicles in road network, the adjacent traffic signal is often connected as a whole, so that the vehicles can travel smoothly. The signal timing parameters are as follows.

1. **Signal cycle of coordinated signal**
   
   Take the intersection with the largest cycle length as the key intersection, and its cycle length is the signal system cycle of the coordinated signal control system.

   \[ C_m = \max \{C_1, C_2, \ldots, C_j\} \]  

   (8)

   Where \( C_j \) is the period length of intersection \( j \) in coordinated signal control, s.

2. **The minimum green time of coordinated phase**
   
   The minimum green time of the coordinated phase of each intersection is the green time of the coordinated phase of the key intersection. It can be defined as

   \[ t_{EGM} = (C_m - L_m)\frac{Y_m}{Y_w} \]  

   (9)

   Where \( L_m \) is the total loss time at key intersections, s; \( Y_m \) is the flow ratio of key traffic flows at key intersections; \( Y_m \) is the sum of the key traffic flow ratio in each phase of the key intersection.

3. **The green time of coordinated phase at non-critical intersection**
   
   The green time of coordinated phase at non-critical intersection should not be shorter than that of key intersection. It can be calculated as

   \[ t_{EG} = C_m - L - \sum_{n=1}^{k} t_{EGn} \]  

   (10)

   Where \( L \) is the total loss time at non-critical intersections, s; \( t_{EGn} \) is the minimum effective green time of the phase \( n \) in the uncoordinated phase of non-critical intersections, s; \( k \) is the total number of uncoordinated phases at non-critical intersections.

4. **The minimum green time of uncoordinated phase**
   
   When uncoordinated phase traffic saturation meets the practical limit \( x_p \) (generally \( x_p = 0.9 \)), the minimum effective green time of the uncoordinated phase at non-critical intersection is given by

   \[ t_{EGn} = \frac{C_s q_n}{S_n x_p} = \frac{C_{mn} v_n}{x_p} \]  

   (11)

   Where \( x_p \) is practical saturation value of uncoordinated phase at non-critical intersections.

### 3. Case study and result analysis

#### 3.1. Case introduction

This paper takes the construction of Chengdu Metro Line 6 on Hegong Road as the analysis object. Hegong Road is one of the north-south main roads in Pixian County. It is surrounded by kindergartens, high schools, hospitals and a number of residential areas, thus, the volume of traffic is large. It is a two-way four-lane road originally. After the occupation by the subway construction, it is changed to two-lane road. As the schematic is showed in figure 1, Zhongxing Avenue is located on the left of Hegong Road and Wangcong Middle Road is on the right. For convenience, we call the intersection on the left as Intersection #1 and Intersection #2 on the right. And the construction areas are located on both sides of the road which are represented by I and II.
3.2. Signal optimization and result analysis

The traffic volume of the construction section of Intersection #1 is 516pcu/h, and the traffic volume of Intersection #2 is 564pcu/h. In order to evaluate the implementation effect of the scheme, this paper analysed some indicators, including vehicle delay, queue length, parking time and parking times.

(1) The average parking time and parking times

After the coordinated signal control, the average parking time of Intersection #1 and Intersection #2 are decreased by 80.5% and 29.5% respectively and 32.8% and 66.5% lower than the optimization of isolated signal control respectively. After optimization, the average parking times of Intersection #1 and Intersection #2 are decreased by 80.8% and 45.1% respectively, and decreased by 34.9% and 63.5% respectively compared isolated signal control. The results are shown in the table 1.

|                     | Average parking time(s) | Average parking times |
|---------------------|-------------------------|-----------------------|
|                     | Intersection #1 | Intersection #2 | Intersection #1 | Intersection #2 |
| Present situation   | 52.77           | 30.68             | 4.10            | 1.90           |
| Isolated signal control | 15.54           | 46.19             | 1.19            | 4.00           |
| Coordinated signal control | 10.12           | 16.84             | 0.80            | 1.34           |

(2) The average delay time and queue length

In addition, this paper used VISSIM to output simulation results in 30-second time interval, and drew the average vehicle delay time and average queue length of the construction section during the simulation time. The charts are shown in figure 2 - figure 5.
As shown in the figure 2 - figure 5, due to the periodic variation of intersection signals, the average delay time and average queue length show periodic fluctuations with time. In addition, it can be seen that without signal control optimization the operation of traffic on the road section is unstable.

After the optimization of isolated signal control, the fluctuation of data in Intersection #1 is more stable than before. It's worth noting that the average delay time and average queue length of Intersection #2 are higher than before. This is because the signal period and green time of Intersection #1 are prolonged when optimized signal timing, which increases the traffic flow from west to east. Besides the coordinate signal control is not realized, so there is a large backlog of vehicles at Intersection #2.

On the basis of isolated single optimization, this paper implemented the coordinate signal control by changing the signal phase difference of intersections. figure 2 - figure 5 shows that, with the coordinate signal control, the average delay time of Intersection #1 changed from 88.15 s to 18.75s and the average queue length decreased from 220.14m to 30.98m. The average delay time of Intersection #2 decreased from 45.88s to 26.38s and the average queue length decreased from 73.68m to 52.44m. The fluctuation of average delay time, average queue length and traffic operation of construction road is more stable, which has been optimized to a great extent. Because Intersection #1 was set as the key intersection, the overall optimization of Intersection #1 is better than that of Intersection #2.

3.3. Analysis of the impact of construction area on road traffic
Since the road traffic system is interrelated, the change of the attribute of construction section will not only affect the traffic operation organization, but also have a certain impact on the traffic signal timing of the intersection. Thus, this paper used VISSIM to simulate traffic operation under difference length of construction working area and transition area and analyzed the influence of the setting length of transition area and working area on traffic. The division of traffic control area is shown in figure 6.

3.3.1. Analysis of the impact of the working area length. This paper took the two-lane as an example in the simulation of the length of the working area of the construction section. The static simulation basic parameters are set as follows: the lane in the construction working area is one-lane, the lane width is 3.5m, and the longitudinal slope of road is 0%. The vehicle composition and traffic volume are based on actual data, the length of transition area is set at 30m. Besides, the speed limit of road and working...
area is 40km/h. This paper selected average queue length, average parking time, total vehicle delay as indicators when the length of working area is set to 400m, 500m, 600m, 700m and 800m respectively. The simulation results are shown in the table 2.

Table 2. Changes in traffic indicators under different length of working area.

| Working area length(m) | Intersection #1 | Intersection #2 |
|-----------------------|-----------------|-----------------|
|                       | Average queue length(m) | Average parking time(s) | Total delay time(s) | Average queue length(m) | Average parking time(s) | Total delay time(s) |
| 400                   | 16               | 26.9            | 37.8              | 15                    | 14.1               | 27.1 |
| 500                   | 16               | 26.1            | 37.6              | 19                    | 20.1               | 37.0 |
| 600                   | 17               | 28.5            | 41.1              | 15                    | 18.7               | 35.8 |
| 700                   | 17               | 28.8            | 41.4              | 12                    | 17.1               | 35.0 |
| 800                   | 16               | 25.4            | 37.8              | 12                    | 17.1               | 34.5 |

According to the table 2, it can be seen that different construction working area length has different influence on the traffic operation of construction section under different signal timing. Overall, the length of working area is longer, the average parking time and delay time is more, and the queue length is longer. Among them, the delay time of the vehicle is affected mostly. For signal timing, the green letter ratio of Intersection #1 is higher than that of Intersection #2. When other conditions remain unchanged, with the increase of the length, the construction of the road section has little influence on Intersection #1. Therefore, as the length of the construction working area increases, the signal cycle of the intersection and the green letter ratio should be appropriately lengthened.

It is worth noting that, the impact of the construction area on traffic operation decreases when the working area length is 800m. This is because the total length of road is about 800 m. Therefore, the road can be directly regarded as a one-lane road, and there is no confluence of vehicles in construction area.

3.3.2. Analysis on the impact of the transition area length. In the simulation of the transition area length in the construction section, this paper selected average queue length, average parking time, total vehicle delay as indicators when the transition area length is set at 30m, 40m, 50m, 60m and 70m respectively. The length of working area is set to 600m and other parameters are consistent with the above. The simulation results are shown in the table 3.

Table 3. Changes in traffic indicators under different transition area length.

| Transition area length(m) | Intersection #1 | Intersection #2 |
|---------------------------|-----------------|-----------------|
|                           | Average queue length(m) | Average parking time(s) | Total delay time(s) | Average queue length(m) | Average parking time(s) | Total delay time(s) |
| 30                        | 17               | 28.1            | 40.5              | 15                    | 18.4               | 35.1 |
| 40                        | 17               | 26.9            | 39.8              | 15                    | 17.1               | 35.0 |
| 50                        | 17               | 24.2            | 40.6              | 14                    | 14.4               | 27.8 |
| 60                        | 15               | 24.3            | 36.7              | 15                    | 17.9               | 35.6 |
| 70                        | 17               | 27.9            | 40.4              | 17                    | 20.1               | 37.0 |

According to the change of index parameter values under different transition area length, it can be seen that the impact of transition area length on road traffic decreases at first and then increases. When the transition area length is set at 50m ~ 60m, the impact of road construction on road traffic is minimal. This is because the too short transition area length can not provide enough space for the confluence of vehicles, and affect the normal operation of vehicles, while the too long transition area length results in a waste of road space and reduces the traffic capacity of the road. Therefore, too short and too long lane change areas will have a negative impact on the operation of vehicles. For signal timing, when the length of transition area is less than 50m or more than 60m, the impact on the delay of the vehicle operation is intensified, and the signal cycle of the intersection and the green letter ratio should be appropriately lengthened.
4. Conclusion

By analyzing the impact of road occupation construction on road traffic, we can evaluate the traffic operation characteristics and service level of road on construction area, so as to take measures to improve the traffic operation.

In this study, this paper first optimizes the signal control of the intersection with the minimum vehicle delay as the target, by using the optimization of isolated signal control and coordinated signal control. The results show that the optimization can effectively improve the traffic organization. Then, the paper uses VISSIM to simulate the traffic operation under the construction activities and analyzes the impact on the intersection under difference length of construction working area and transition area. The results show that without exceeding the length of the road, there is a negative correlation between the length of construction area and the traffic operation, especially the delay time of vehicle. The results also suggest that the transition area has the least impact on traffic operation when its length is set at 50m ~ 60m. Meanwhile, as the length of the construction area increases, the intersection with higher green letter ratio is less sensitive to the change of length. The overall results help to identify the recommended length of construction area and improve the road traffic operation efficiency.

However, there are also some weaknesses in this study. One major limitation is the complexity of construction area. Although we select the semi-closed construction area which is representative for analysis, irregular setting of construction area is still an unavoidable issue for studies. The findings in this paper can provide guidance for those regions with similar construction area, and road network. In addition, there is still room for improvement regarding the different type of construction area.

References

[1] Daamen, W., van Arem, B., Bouma, I. (2011). Microscopic dynamic traffic management: Simulation of two typical situations. 14th International IEEE Conference on Intelligent Transportation Systems (ITSC), Washington, DC. pp: 1898-1903.

[2] Fei, L., Zhu, H. B., & Han, X. L. (2016). Analysis of traffic congestion induced by the work zone. Physica A: Statistical Mechanics and its Applications, 450: 497-505.

[3] Wen, J.X., Meng, Q. (2011). Modeling speed-flow relationship and merging behavior in work zone merging areas. Transportation research part C: emerging technologies, 19(6): 985-996.

[4] Xiao, D.Q. (2018). Research on micro traffic simulation of road work zone. Wuhan. Huazhong University of Science and Technology.

[5] Li, Y. X., Ding, Q., Kong, Y. Y. (2019). Modeling and analysis of the impact of urban and rural road reconstruction construction on vehicle capacity. Advances in Transportation Studies, an International Journal, v1, n Special Issue: 97-110.

[6] Bhutani, R., Ram, S., & Ravinder, K. (2016). Impact of metro rail construction work zone on traffic environment. Transportation Research Procedia, 17: 586-595.

[7] Sun, R.X. (2016). A study of the capacity of signalized intersection with work zone based on modelling and simulation. Chengdu. Southwest Jiaotong University.

[8] Donnelly, J., Papayannoulis, V. (2004). A Microscopic Traffic Simulation Model of West Midtown Manhattan. Ninth TRB Conference on the Application of Transportation Planning Methods. Baton Rouge Louisiana. pp: 214-222.

[9] Zhang. W. (2015). Traffic organization of a road intersection during the occupying-road construction. Transportation Science & Technology, 6: 147-150.

[10] Huang, J.W. (2017). The study of optimization of single point road intersection organization and signal control during construction. Xi’an. Chang’an University.