DOI: 10.23977/acss.2023.071012
ISSN 2371-8838 Vol. 7 Num. 10

Optimization of Signal Intersection Delay Analysis—Taking Zhongshan East Road and Jianshe Street in Shijiazhuang City as an Example

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Keywords: Intersection; capacity delay; analysis signal timing

Abstract: Intersection is an important part of urban road traffic system, and its existence is of great significance. The design and management of intersections directly affect the traffic capacity and operation efficiency of the entire urban road. Improving the traffic capacity of intersections and reducing vehicle delays are beneficial to the traffic capacity of the entire urban road. This paper takes the intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City as the research object, and analyzes its traffic capacity and delay in view of the problems at the intersection. The traffic flow model is used to analyze the traffic capacity of the intersection, and the design capacity of each phase of the intersection is obtained. According to the traffic delay analysis, the congestion of the intersection is calculated, and the congestion problem of the intersection is found. Finally, the Webster method is used for signal timing and other methods to optimize the intersection, so as to improve the traffic capacity of the intersection of Zhongshan East Road and Jianshe South Street.

1. Introduction

Intersections occupy a very important position in urban traffic[1]. The road traffic network [2] is expanding and complicated, the number of intersections is also increasing, and the traffic flow is also increasing. The demand for transportation services is also growing. Therefore, the study of intersections is of great significance to improve the efficiency of urban traffic, reduce congestion [3], optimize traffic organization and improve traffic safety [4]. For intersections with signal lights, the cycle of signal lights, the green signal ratio of signal cycle, and the distribution of traffic light time will affect the traffic capacity of intersections.

Many scholars at home and abroad have conducted in-depth research on the capacity of intersections. A series of scholars have compared the research differences from different angles, and concluded the necessity of implementing capacity measurement and optimization. Wang et al. [5] used the improved traffic flow headway distribution function to obtain a variety of different theoretical model formulas; Gao and Wang [6] studied the driver 's response from the geometric characteristics of the intersection, and established the critical gap estimation model by using the vehicle dynamic performance; By pre-organizing the upstream vehicles at the intersection and periodically changing the functions of all or most of the imported lanes, Zheng et al. [7]controlled the space utilization efficiency of the imported lanes by setting restrictions. The array intersection with the idea of pre-signal control can realize the pre-organization of the upstream vehicles at the intersection and periodically change the functions of all or most of the imported lanes; Ma et al. [8] established a bi-level optimization model, introduced the coordinated control of main and pre-signals into the signal timing scheme, and achieved the optimization goals of minimum average vehicle delay and minimum green light interval; Ma et al.[9] for urban road traffic mixed phenomenon serious problems. Through the investigation and analysis of the traffic operation characteristics of urban road signal control intersections, the calculation methods of saturated headway and traffic capacity of entrance lanes for straight left vehicle mixed and small car and bus mixed are studied. The calculation method of traffic capacity of mixed entrance lane based on steering ratio and bus ratio is established; Ding et al. [10] derived and analyzed the branch capacity model under ideal conditions, and studied it by using the random variable method. Using the Markov method, the secondary road capacity model under the condition of mixed traffic flow with multiple steering and multiple models is established; Webster in the UK analyzed and studied the vehicle delay, traffic capacity and signal timing through investigation, and established the corresponding model; Chen et al. [11] integrated random analysis to improve the traffic capacity of intersections, improve the traffic capacity of the intersection.

Above all, the current research on intersections is relatively mature, mainly through the signal timing to optimize the intersection to improve the traffic capacity, using the vissim model to simulate the optimized intersection to verify whether the optimization method is reasonable. This paper will take the intersection of Zhongshan East Road and Jianshe Street in Shijiazhuang City as the main research object, and use a variety of methods to find out the problems existing in the intersection of Zhongshan East Road and Jianshe Street in Shijiazhuang City, and use webester signal timing method and other optimization measures to propose effective solutions to improve the traffic safety of the intersection.

2. Investigation on the intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City

2.1. Geographic position

The intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City is located in the city center. It is an extremely important traffic artery in Shijiazhuang City. To the west is the North China Mall (large shopping plaza); There is also a Chang'an Park in the north, and there are middle schools nearby. There are many pedestrians and non-motor vehicles and pedestrian factors are too large; The city center of Shijiazhuang City in the west is full of places for eating, shopping and playing, and the daily traffic volume of people and cars is very large. Nowadays, the number of private vehicles has also increased, and more and more traffic problems have emerged at this intersection, such as pedestrian non-compliance with traffic rules, vehicle congestion problems, non-motorized vehicle interference. Therefore, the cause of congestion is not only the increase of vehicles, but also the large number of pedestrians and some pedestrians do not comply with the traffic rules.

2.2. Lane information

The intersection is two-way nine lanes in the east-west direction and two-way ten lanes in the north-south direction. At the east entrance, there are three straight lanes, two left-turn lanes, one right-turn lane and three entrances (including a bus lane);At the west entrance, there are three straight lanes, a left-turn lane, a right-turn lane and four entrances (including a bus lane);At the south entrance, there are three straight lanes, two left-turn lanes, one right-turn lane and four entrances; At the north entrance, there are three straight lanes, two left-turn lanes, one right-turn lane and four entrances (including a bus lane).As shown in Figure 1.

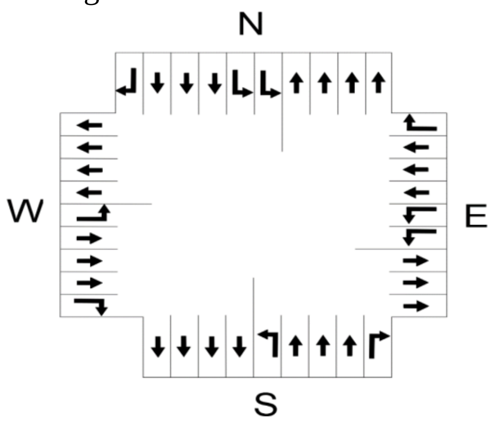

Figure 1: Plan of Zhongshan East Road and Jianshe South Street in Shijiazhuang City

2.3. Traffic signal control situation

After on-site inspection, the status of traffic lights at the intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City is as follows: A period of the intersection signal light is 178 s, and a period of the signal light is divided into four phases. The first phase is the east-west import straight and right turn traffic; The second phase is the east-west import left turn traffic; The third phase is the north-south import straight and right turn traffic; The fourth phase is the north-south import left turn traffic. The signal timing diagram is shown in Fig. 2.

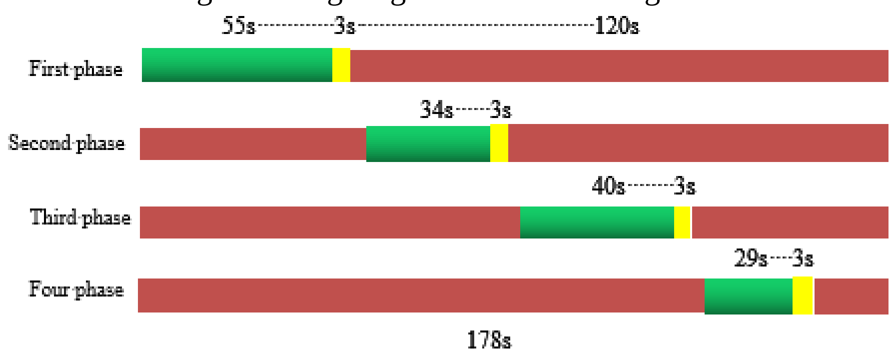

Figure 2: Signal timing diagram

2.4. Traffic flow at intersections

The intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City is an intersection in Shijiazhuang City. Trucks and locomotives are not allowed to pass through the city, but there are buses. Therefore, all the imported vehicles are converted into standard models and summarized. The survey period of this article is 5:30-6:30 p.m., which is the peak period of off-duty.

The data collected from the survey are summarized to obtain the following table. As shown in Table 1. The traffic volume of each import in all directions is shown in Fig. 3.

Table 1: The actual traffic volume of motor vehicles at the intersection of the 13th day.

direction	traffic volume
West entering	1404
East entering	1396
South entering	1506
North entering	1517

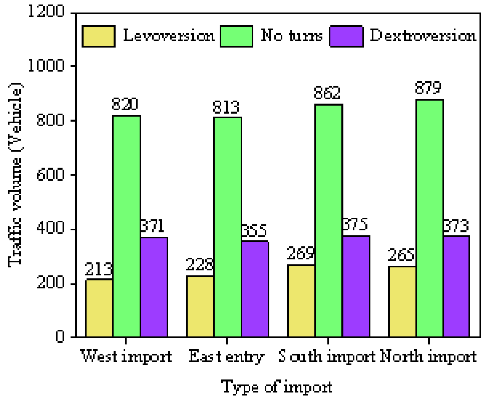

Figure 3: Traffic volume of left-turn, straight-line and right-turn at each entrance

Through Fig. 3, it can be concluded that the intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City accounts for a large proportion of straight traffic during the peak period. According to the field survey, it is found that in the actual situation, pedestrians will follow the straight green light through. Pedestrian capacity at peak times affects vehicle traffic, and the signal cycle at the intersection also affects capacity.

3. Capacity calculation and delay analysis of intersection

3.1. Calculation ideas

(1)Using the traffic capacity of the intersection in ' Traffic Engineering ', the traffic capacity of the signal-controlled intersection is calculated by the method specified in the actual specification of urban roads in China.

$$C_s = \frac{3600}{T}\left(\frac{t_g - t_0}{t_i} + 1\right)\phi \tag{1}$$

In the -type, C_s is the design capacity (vehicle/hour) of a straight lane.;T is the signal light cycle (s);t_g is the green time (s) during the signal weekly period;t_0 is the time (s) when the first car starts and passes the stop line after the green light is turned on (s).2.3 s can be used;t_i is the average time (s/vehicle) that a straight or right-hand vehicle passes through a parking line.small car take = 2.5s, large car take = 3.5s;Φ is the reduction factor, available 0.9.

(2) Due to Zhongshan East Road and Jianshe South Street intersection lane has a dedicated left turn and dedicated right turn lane. Therefore, the design capacity of the approach can be calculated according to the following formula:

$$C_{elr} = \sum C_s / \left(1 - \beta_1 - \beta_2\right) \tag{2}$$

In the -type,C_{elr} is the design capacity of the entrance road when there are special left turn and special right turn lanes;$\sum C_s$ is the sum of the capacity of the design of the straight lane;$\beta_1\beta_r$ is the proportion of left and right transfer vehicles in the import road.

(3) Checking whether reduction is needed. If $C_{le} > C'_{le}$ $C_{le} > C'_{le}$ needs to be reduced, and the design capacity is recalculated. The formula is:

$$C_e' = C_e - n_s\left(C_{le} - C_{le}'\right) \tag{3}$$

In the -type,C_e' is the design capacity of the entrance after reduction;C_e is the design capacity of the entrance;n_s is the number of various straight lanes on the surface;C_{le} is the design throughput of left turn vehicle on the road at the entrance of this side;C_{le}' is the number of left-turning vehicles (vehicles / hour) on the opposite side without reducing the designed capacity of various straight lanes in this side.When the intersection hour is 3n, the big hour is 4n, n is the number of signal cycles per hour.This intersection takes 4n.

3.2. Calculation of intersection capacity

According to the above calculation, the design capacity of each entrance can be obtained, and the saturation of each direction can be obtained by comparing with the actual capacity. The integrated data are shown in Table 2.

Table 2: Saturation analysis in all directions.

direction	West entering	East entering	South entering	North entering
traffic volume	1404	1396	1506	1404
design capacity	1075	1030	1216	1260
degree of saturation	1.3	1.1	1.2	1.1

Road saturation (V/C) is an important index to measure the level of urban road traffic service. Domestic cities generally adopt the service level division standard as shown in Table 3.

Table 3: Service level table.

service level	V/C value range	traffic condition
first-order	V/C= 0-0.6	the smooth flow of traffic
second order	V/C= 0.6-0.8	A little congestion
three-stage	V/C= 0.8-1.0	road congestion
four-stage	V/C> 1.0	serious congestion

Combined with the data of Table 2 and Table 3, it is found that the V/C of the four imports is > 1.0, which is a four-level service level. Serious road congestion has occurred during the off-peak hours. The saturation of each direction of the intersection is relatively large, and necessary measures should be taken to alleviate the congestion.

3.3. Intersection traffic delay calculation

The point sample method is used to collect the data, and then the intersection delay calculation formula learned in traffic engineering is used to calculate the delay[12].The calculation formula of intersection delay is as follows :

$$D = S \times T \tag{4}$$

$$\overline{D_i} = \frac{D}{S_i} \tag{5}$$

$$\overline{D_j} = \frac{D}{V_j} \tag{6}$$

$$\lambda = \frac{S_i}{V_j} \times 100\% \tag{7}$$

In the -type, D is the total delay; S is total number of stops; T is sampling time interval; $\overline{D_i}$ is Sampling time interval; S_i is number of parked vehicles; $\overline{D_j}$ is the average delay of each entrance vehicle; V_j is entrance traffic volume; λ is percentage of parked vehicles.

3.4. Data collation and delay analysis

According to the above calculated data, Table 4 is obtained.

Table 4: Data collation table of each import delay.

	West entering	East entering	South entering	North entering
total delay	10680	7695	10155	6375
Average delay of parked vehicles	61.3	22.8	57.7	22.1
Average delay of entry vehicles	43.6	18.1	45.1	17.0
Percentage of parked vehicles	71%	79%	78%	77%

According to the U.S. ' Road Capacity Manual ', the level of service at signalized intersections should meet the following standards, as shown in Table 5.

Table 5: Service level standard of signalized intersection.

service level	Parking delay per vehicle	operating condition
A	0-5.0	current of free traffic
B	5.1-15.0	Stable traffic flow (slight delay)
C	15.1-25.0	Stabilize traffic flow (can accept delay)
D	25.1-40.0	Close to unstable traffic flow
E	40.1-60.0	Unstable traffic flow
F	>60.0	forced flow

Through systematic statistics and in-depth research, we can draw the conclusion :The north and east entrances are at the level of C service level, which indicates that the passenger flow of the section is considerable and belongs to stable traffic flow (can accept delay);In the west import, the average delay time is about 61.3 s, in the F level of service level, the operation belongs to the compulsory traffic flow ; in the south entrance, the average delay of the traffic volume is 57.7 s, which belongs to the E-level service level, and the operation is unstable traffic flow. From the above, it can be concluded that the delay of the west and south entrances of the intersection is relatively large, and certain measures are needed to optimize it.

4. Problems at intersections and their optimization measures

4.1. The main problems of intersection

According to data analysis and field investigation, through the calculation of intersection capacity and delay analysis, it is found that the problem of the intersection is unreasonable signal timing.

According to the calculation of traffic capacity, it is found that the saturated flow rate in all directions of the intersection is too large, causing congestion at the intersection. It is found that the cycle of the signal light at the intersection and the time of the green light at each phase have a great influence on the actual traffic flow. The unreasonable cycle setting of the signal timing makes the traffic capacity of the south and west entrances of the intersection significantly reduced, and the delay of these two imported vehicles is forced traffic, which is the main problem at the intersection.

4.2. Intersection optimization measures

According to the above data, the intersection of Jianshe South Street and Zhongshan East Road in Shijiazhuang can be optimized in the following aspects.

4.2.1. Signal timing optimization

(1) Thinking: Using Webster's method [13]

① The total waste of signal time:

$$L = \sum_k \left(L_s + I - A\right)_k \tag{8}$$

$$I = A + AR \tag{9}$$

In the -type, L is the total loss time of the signal;L_s is the loss time of vehicle start-up, and 3 s can be taken when there is no data ;I is the green light interval time;A is yellow light time, usually 3s ;AR is all red light time ;K is the number of green light intervals in a cycle.

② The sum of flow ratio:

$$Y = \sum_{j=1}^{j} max\left[y_j, y_j, \ldots\right] = \sum_{j=1}^{j} max\left[\left(\frac{q_d}{s_d}\right)_{j,} \left(\frac{q_d}{s_d}\right)_{j,} \ldots\right] \tag{10}$$

In the -type,Y is the sum of the maximum flow ratio y_i of each signal phase that constitutes the period ;j is the number of phases in a period ;y_j is the j phase flow ratio;q_d is the design traffic volume ;S_d is the design of saturated flow.When Y > 0.9, it is necessary to optimize and improve the design of the entrance or signal timing.

③ The best signal cycle with the least vehicle delay:

$$C_0 = \frac{1.5L + 5}{1 - Y} \tag{11}$$

④Total effective green time per cycle:

$$G_e = C_0 - L \tag{12}$$

⑤ The green time of each phase:

$$g_i = \frac{y_i}{Y}(C_0 - L) \tag{13}$$

⑥ The time of each phase green light after optimization:

$$g_i = g_{ej} - A_j + l_j \tag{14}$$

4.2.2. Optimized signal timing

According to the Webster method, the green light time of each phase is obtained:

$$g_1 = g_{el} - A_1 + l_1 = 44 - 3 + 3 = 44(s)$$

$$g_2 = g_{e2} - A_2 + l_2 = 28 - 3 + 3 = 28(s)$$

$$g_3 = g_{e3} - A_3 + l_3 = 50 - 3 + 3 = 50(s)$$

$$g_4 = g_{e4} - A_4 + l_4 = 28 - 3 + 3 = 28(s)$$

The optimized signal timing diagram is obtained, as shown in Figure 4:

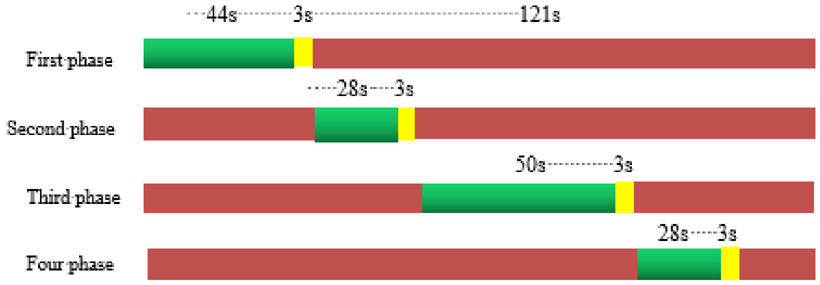

Figure 4: The optimized signal timing diagram

4.2.3. Other optimization measures

The intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City is in the center of the city and the surrounding building layout has been unable to change. Pedestrians and non-motor vehicles have also caused congestion at the intersection, so it is optimized through other aspects.

(1) Regulate the behavior and route of non-motor vehicles and pedestrians so that they do not change lanes at will, do not run red lights and walk non-motorized lanes. Many pedestrians will wait on the crosswalk instead of on the steps when waiting for a red light, which will cause inconvenience for non-motor vehicles. A small number of pedestrians running red lights should regulate the behavior of pedestrians to alleviate the pressure of traffic.

(2) Increase traffic police through traffic control. During the peak period, due to the excessive number of motor vehicles and the non-standard driving of non-motor vehicles, congestion is caused. At the intersection, auxiliary police control is added to guide and manage vehicles and pedestrians, reduce traffic accidents and pedestrians or vehicles that do not comply with traffic regulations to

alleviate traffic congestion.

4.3. Comparative analysis after optimization

With the help of VISSIM simulation platform[14], the optimized intersection of Zhongshan East Road and Jianshe South Street is simulated.

Through multiple simulations, the average delay after optimization of the intersection of Zhongshan East Road and Jianshe South Street is obtained. The vehicle delay at the optimized intersection is compared with that before optimization to obtain the following table. As shown in Figure 5.

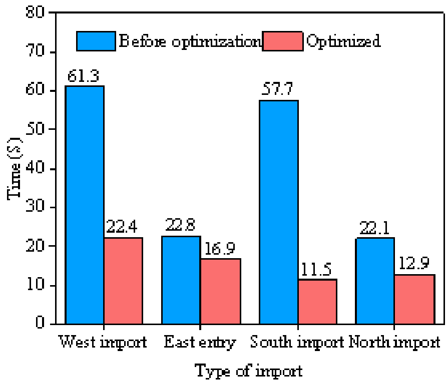

Figure 5: Comparison of delays before and after optimization

After optimization measures, the traffic capacity before and after optimization is compared by using the formula in traffic engineering to obtain Table 6.

Table 6: Comparison of design capacity before and after optimization.

direction	West entering	East entering	South entering	North entering
Traffic capacity before optimization	1075	1030	1216	1260
Optimized traffic capacity	1873	1753	1713	1781

Through Figure 5, it can be compared that the delay of vehicles at the optimized intersection is significantly reduced, especially at the west and south entrances. The average delay time of the imported vehicles in the west is reduced from 61.3 s to 22.4 s, and the service level is reduced from F level to C level, indicating that the import is reduced from the forced traffic flow to the stable traffic flow; The average delay time of the imported vehicles in the south import is reduced from 57.7 s to 11.5 s, and the service level is reduced from E level to B level, indicating that the import is reduced from forced traffic flow to stable traffic flow.

Through Table 6, it can be clearly seen that the traffic capacity of the intersection after signal timing optimization is significantly improved. Through signal timing, it can be found that the design capacity of the four entrances is improved, and the passing rate of the vehicle is also increased, which alleviates the congestion problem caused by the signal cycle.

5. Conclusions

This paper takes the intersection of Zhongshan East Road and Jianshe South Street in Shijiazhuang City as the research object, and uses the traffic flow model learned in traffic engineering to calculate the traffic capacity of the intersection. Through the method of field survey, the traffic flow and traffic signal cycle time of motor vehicles in each phase of the intersection and the traffic volume of the intersection are obtained. The traffic flow model is used to analyze the capacity of the intersection, and the design capacity of each phase of the intersection is obtained. According to the traffic delay analysis, the congestion at the intersection is calculated, and the causes of the congestion at the intersection are analyzed. Finally, Webster method is used for signal timing and other methods to optimize the congestion problem at the intersection.

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