Signal timing optimization design of cross intersection-- A Case study of The intersection of Minzhu South Road and Fengshou Road in Jiaozuo City

Jiangfan Yang1,a, Guolong Zhang1, Meiheng Li1
1Energy Science and Engineering, Henan Polytechnic University ,Jiaozuo Henan, China
a212002020066@home.hpu.edu.cn

Abstract. The capacity of intersection affects the maximum capacity of road to a certain extent. The traffic capacity of the intersection can be improved to some extent by optimizing and adjusting the parameters of the signal timing model. Taking the cross-type intersection at the intersection of Minzhu South Road and Fengshou Road in Jiaozuo City as the research background, this study optimizes the signal timing design for the current intersection, optimizes the signal timing design by using Webster algorithm, and conducts simulation by using traffic simulation software VISSIM. The results showed that the average delay at the intersection was reduced by nearly seven seconds.

1. Introduction
Intersections are nodes of the urban road traffic network, intersection and diversion occur frequently in different directions of traffic flow, making the intersections become the “bottleneck” of the road network capacity[1]. Therefore, solving the traffic capacity of intersections scientifically is the key to improve urban traffic efficiency, improve urban traffic congestion and ensure traffic safety.

A correct and reasonable timing scheme for intersection signals can not only improve the capacity of intersections, evacuate the traffic and ensure smooth traffic, but also improve the effect of traffic safety[2]. Therefore, one of the keys to solve the traffic problems at intersections is to set up a reasonable timing scheme for intersection signals.

In recent years, experts and scholars have also studied and optimized the signal timing method. Webster[3] in the UK has proposed a single performance indicator signal control method, which takes the delay of vehicles at intersections as the optimization objective. However, the average delay model in the unsaturated state proposed by Webster is still widely used. The American Schmocker established a multi-objective optimization model of intersection signal timing based on the average delay time, the average number of stops and the traffic capacity of vehicles, and used the multi-objective genetic algorithm based on Bellman-Zadeh fuzzy logic to solve the optimization problem. Domestic scholar Junjie Geng[4] selected traffic performance indexes, established signal timing multi-objective robust optimization model under periodic duration disturbance, and proposed MDASOI algorithm for multi-attribute decision analysis to effectively reduce traffic flow delay at intersections and improve operation efficiency.

2. Investigation and analysis of current situation
According to the current signal timing scheme at the intersection of Minzhu South Road and Fengshou
Road in Jiaozuo city, this paper will optimize and improve the signal timing scheme according to the actual survey data and the situation of pedestrian crossing time, so as to improve the road capacity and reduce vehicle delays.

2.1. Intersection traffic and geometry status
The intersection of Minzhu South Road and Fengshou Road is a cross-shaped intersection, both of which have six two-way lanes. This intersection is also the closest intersection to the nearby large shopping malls, and there are multiple residential areas around this section of the road, so the pedestrian traffic volume and vehicle flow are high. Minzhu South Road is a north-south road, with a width of 12m at the entrance and 11.25m at the exit. Fengshou Road is an east-west road, with a width of 12m at the entrance and 11.25m at the exit. The current lane layout at the intersection is shown in Figure 1.

![Figure 1: Lane layout at the intersection of Minzhu South Road and Fengshou Road](image)

2.2. Current situation of traffic flow and signal timing at intersections
The entrance road at the intersection of Minzhu South Road and Fengshou Road is composed of a left-turn special lane and three straight lanes. The traffic flow at the intersection during the evening rush hour (17:30~18:30) is investigated. At the same time. The traffic volume at the intersection is generally observed by manual observation, and the traffic flow in all directions at the intersection is shown in Figure 2.
The current situation of the intersection adopts the four-phase control scheme, yellow light 3s, cycle time 158s, and the current timing scheme is shown in Figure 3.

2.3. Intersection service level
The service level of signal-controlled intersections refers to the traffic service quality provided by signal-controlled intersections to road users and the satisfaction degree of road users to the services provided by intersections. Generally, service levels at signalized intersections are measured and assessed by delays. In order to directly measure the service level of the optimized road intersection design, according to the service level standard provided by the US road Capacity Manual[5] and in combination with the characteristics of the high saturation of the intersection in this paper, VISSIM simulation method was adopted to simulate the traffic situation of the intersection and the evaluation results were obtained. The results were calculated and counted as shown in Table 2 below.

| Import   | flow  | Average delay (s) | Average queue length (m) | The service level |
|----------|-------|-------------------|--------------------------|-------------------|
| East import | left  | 42.3              | 2.4                      | D                 |
|          | straight | 44.1              | 23.0                     | D                 |
| West import | left  | 60.2              | 16.7                     | E                 |
|          | straight | 54.6              | 43.5                     | D                 |
Based on the above results, the following conclusions can be drawn.

a) The average delay at the intersection of Minzhu South Road and Fengshou Road (the right turn delay is not included) is 41.9s, which requires optimization.

b) In the straight direction, the east and west entrance has a big delay and the average queue length is also large. The main reason is that the traffic flow of the east and west connecting the national highway is large, and the green time at signal timing is the same as that of the south and north entrance.

c) In the left-turn direction, the queue length of the south and north entrance road is not long and the delay is great, mainly because the signal cycle time is too long, leading to a long waiting time for left-turn vehicles.

To sum up, the main reason for intersection congestion is the delay caused by the unreasonable timing of signal lights. Moreover, at the intersection of Minzhu South Road and Fengshou Road near the nearby shopping malls, there is a large flow of pedestrians and non-motor vehicles, and the safe passage of pedestrians on the crosswalk is affected by the driving of non-motor vehicles. Therefore, it is considered to optimize the timing of signals at the intersection.

3. Optimization design of intersection signal control

3.1. Content and method of signal timing scheme design

Intersection signal timing control has a great impact on the capacity of the intersection. Many models and calculation methods have been proposed from different perspectives and scenarios at home and abroad. So far, timing methods for timing signals mainly include the Webster’s method [6] in the UK, the ARRB method [7] in Australia and the HCM method [8] in the US. In China, there are mainly “parking line method” and “conflict point method” [9].

In order to alleviate the delay at the intersection and improve the road capacity, the most classic British Webster method is adopted here to time the intersection signals. The specific methods are as follows:

3.1.1. Determine design traffic volume

When determining the design traffic volume, the corresponding design traffic volume should be determined according to the time-varying law of the daily traffic volume at the intersection, and the different flow direction of the intersection and the entrance in each period should be given respectively. The calculation formula is as follows:

\[ q_{dmm} = 4 \times Q_{15mn} \]

Where: \( q_{dmm} \) — The design traffic volume (pcu/h) of inlet channel m and flow direction n in the timing period; \( Q_{15mn} \) — In the timing period, the highest flow rate (pcu /15min) in the peak hour of inlet m and flow direction n.

If the highest flow rate of 15min is not observed during the investigation, it can be estimated by the following formula:

\[ q_{dmm} = \frac{Q_{mn}}{(PHF)_{mn}} \]

Where: \( Q_{mn} \) — In the timing period, the peak hour traffic volume (pcu/h) flowing from the inlet channel m to n; \( (PHF)_{mn} \) — In the timing period, the peak hour coefficient of inlet channel m and flow direction n is 0.75 for the main inlet channel and 0.8 for the secondary inlet.
3.1.2. Saturation flow calculation
The calculation of saturation flow was completed at the time of capacity calculation in this paper and will not be repeated here.

3.1.3. Calculation of timing parameters
Optimum cycle time

\[ C_0 = \frac{1.5L + 5}{1 - Y} \]  
(3)

Where: \( L \) — Total signal loss time; \( Y \) — Sum of flow ratios.

Total signal loss time

\[ L = \sum (L_s + I - A)_k \]  
(4)

Where: \( L_s \) — The starting loss time should be measured, and 3s can be taken when there is no measured data; \( A \) — Yellow light duration, locating 3s; \( I \) — Time between green lights (s); \( k \) — The number of green light intervals in a cycle.

Sum of flow ratios

\[ Y = \sum \max \left[ y_j, y_j', \ldots \right] \]
\[ = \sum_j \left[ \frac{q_d}{s_d} \right]_j \left( \frac{q_d}{s_d} \right)_{j'} \ldots \]  
(5)

Where: \( Y \) — Sum of each maximum flow ratio \( Y \) value of all signal phases constituting the period; \( j \) — The number of phases in a period; \( y_j \) — The flow ratio at phase \( j \); \( q_d \) — Design traffic volume (pcu/h); \( s_d \) — Design saturation flow rate (pcu/h).

When the calculated \( Y \) value is greater than 0.9, the inlet channel design or/and signal phase scheme shall be improved and redesigned.

Total effective green time

The total effective green time of each cycle is calculated by the following formula.

\[ G_e = C_0 - L \]  
(6)

Effective green time of each phase

\[ g_{ej} = G_e \frac{\max \left[ y_j, y_j', \ldots \right]}{Y} \]  
(7)

The green letter ratio of each phase

\[ \lambda_j = \frac{g_{ej}}{C_0} \]  
(8)

Each phase shows the green time

\[ g_j = g_{ej} - A_j + I_j \]  
(9)

Where: \( I_j \) — the starting loss time at phase \( j \).

Minimum green time

\[ g_{\min} = 7 + \frac{L_p}{V_p} - I \]  
(10)

Where: \( g_{\min} \) — Minimum green time (s); \( L_p \) — Length of pedestrian crossing(m); \( V_p \) — Pedestrian crossing speed, 1.0~1.2m/s; \( I \) — Time between green lights (s).
The calculation shows that the green time is less than the minimum green time required for pedestrians to cross the street, so the duration of signal cycle should be extended (in order to meet the minimum green time), and the calculation of each timing element should be performed again.

3.2. Optimize the detailed design of signal timing
According to the previous investigation and analysis, the phase setting of the existing signal timing is relatively reasonable, which can meet the current traffic situation at the intersection. Therefore, the Webster method is considered to optimize the design of the existing signal timing scheme without changing the signal phase. According to the data obtained from the previous investigation, the parameters of signal timing were calculated. The signal timing scheme is obtained under the requirement of the minimum green light time to meet the pedestrian crossing demand, as shown in Figure 4 below.

![Figure 4: Improved signal timing diagram at the intersection of Minzhu South Road and Fengshou Road](image)

VISSIM micro-simulation software was used to simulate the optimized intersection scheme. By comparing table 2, it can be seen that the average delay of the optimized intersection was 36.7 seconds, which was nearly 7 seconds less than before the optimization, and the overall optimization effect was significant.

| Import | Flow   | Average Delay (s) | Average Queue Length (m) | The Service Level |
|--------|--------|-------------------|--------------------------|------------------|
| East   | Left   | 44.9              | 2.4                      | D                |
|        | Straight| 36.4              | 19.4                     | D                |
| West   | Left   | 49.4              | 10.6                     | D                |
|        | Straight| 38.6              | 32.3                     | D                |
| South  | Left   | 41.2              | 14.2                     | D                |
|        | Straight| 49.1              | 21.0                     | D                |
| North  | Left   | 42.6              | 15.9                     | D                |
|        | Straight| 51.5              | 16.7                     | D                |

4. Conclusion
This paper mainly makes an optimal design for signal timing at the cross intersection of Minzhu South Road. Based on the investigation and analysis of the existing problems in the current traffic state, focusing on the characteristics of large slow traffic flow in this section of the road, the Webster method is used to optimize and improve the timing scheme of intersection signals. The results show that the average delay at the intersection is reduced by nearly 7 seconds, and the optimization effect is significant. The optimization scheme and related measures can provide effective reference for alleviating the current increasingly serious urban road congestion.

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