Intersection Signal Timing Optimization based on Webster Timing Method

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Abstract. The traffic conditions at the intersection have an increasingly high impact on the normal operation of the road. Improving the signal timing can effectively improve the congestion at the intersection. Taking Xi'an North Street intersection as an example, this paper improves signal timing by Webster timing method. The results before and after the improvement are simulated by VISSIM simulation software. The delay, queue length, parking time and parking times before and after the improvement are compared and analyzed, and the conclusion is drawn. The simulation results show that after optimizing the signal timing, the vehicle delay is reduced by 25.24%, the parking time is reduced by 35.16%, and the maximum queue length, average queue length and number of stops are also reduced. It can be seen that the optimized intersection operation status significant improvements have been made.

1. Introduction

With the development of the economy and the prevalence of private cars, the traffic situation has become a big problem troubling people at present and even in the future[1]. Traffic jams are becoming more and more common phenomenon, especially at road intersections, becoming the first problem to be solved. Signal timing at intersections is an important way to solve this problem. Optimizing signal timing is conducive to solving traffic congestion, beautifying urban environment and facilitating people's work and life[2].

Vissim, a traffic simulation software, was used to evaluate the schemes before and after the signal timing optimization at the intersection, and the optimal scheme was selected[3]. This paper takes the intersection of Xi'an North Street as an example.

2. North street traffic and traffic flow status

2.1. Status of intersection

The north street intersection is located in the center of Xi'an city, between the new urban area and Liancheng District, surrounded by hospitals, hotels, schools and banks. It is also the transfer stop of Metro Line 1 and Line 2. The traffic volume of people and vehicles is relatively large, and it is a very important intersection.
2.2. Road situation
Intersection of the main road is a two-way 12 lanes with two non-motorized lanes, a sidewalk; The secondary road is a two-way road with 8 lanes, 2 non-motorized lanes and 1 sidewalk. The lanes are 3.5m wide, the non-motorized lanes are 2m wide, and the sidewalks are 2m wide. The main and secondary roads have a central divider, and there is a dividing bar between the motorway and the sidewalk to ensure the safety of pedestrians.

2.3. Traffic status
The traffic flow statistics of the intersection are carried out according to the east, west, south and north entrances respectively. The intersection of the north street and the west fifth road is a cross intersection, and the traffic flow directions of each entrance are divided into straight, left and right turns. The unit of traffic flow in the table is pcu/h, that is, traffic flow per hour[4].

| entrance     | traffic flow | traffic flow (pcu/h) |
|--------------|--------------|----------------------|
|              | Passenger car | Bus                  |
| North entrance | Go straight | 708                  | 120 |
|              | turn left    | 414                  | 48  |
|              | turn right   | 521                  | 72  |
| South entrance | Go straight | 1014                 | 138 |
|              | turn left    | 384                  | 12  |
|              | turn right   | 138                  | 48  |
| East entrance  | Go straight  | 408                  | 12  |
|              | turn left    | 168                  | 12  |
|              | turn right   | 336                  | 36  |
| West entrance   | Go straight  | 816                  | 12  |
|              | turn left    | 120                  | 12  |
|              | turn right   | 540                  | 60  |

2.4. Signal cycle
There are four phases in the phase control of vehicle right of passage. The first phase is north-south straight and dextroversion, the passage time is 99s; The second phase is straight east-west and right-turn, and the passage time is 62s; The third phase is the left turn of the north entrance and the left turn of the south entrance, and the passage time is 29s; The fourth phase is the east import left turn and the west import left turn, the transit time is 24s. As shown in the table below.
Table 2. Signal timing of north street

| Phase               | The First Phase | The Second Phase | The Third Phase | The Fourth Phase |
|---------------------|----------------|-----------------|----------------|-----------------|
| Green time /s       | 99             | 62              | 29             | 24              |
| Yellow light time /s| 5              | 5               | 5              | 5               |
| Signal loss time /s | 3              | 3               | 3              | 3               |

2.5. Vissim simulation results

According to the above road status, traffic flow status and signal timing, we can get delay time, queue length, parking time and parking times by Vissim simulation[5]. The simulation results are shown in the following table.

Table 3. Simulation evaluation results of Vissim status quo

| Node   | Maximum queue length /s | Average queue length /s | Parking times /time | Number of passing vehicles / unit | Delay time /s | Parking time /s |
|--------|--------------------------|-------------------------|--------------------|----------------------------------|---------------|-----------------|
| 1      | 116.3                    | 35.4                    | 0.92               | 18                               | 27.4          | 17.5            |
| 1      | 116.3                    | 35.4                    | 1.35               | 10                               | 40.8          | 34.5            |
| 1      | 116.3                    | 35.4                    | 0.83               | 37                               | 27.2          | 16.7            |
| 1      | 0.0                      | 0.0                     | 0.40               | 68                               | 14            | 0.0             |
| 1      | 52.1                     | 10.9                    | 0.64               | 20                               | 20.8          | 13.5            |
| 1      | 52.1                     | 10.9                    | 0.80               | 8                                | 24.8          | 51.2            |
| 1      | 52.1                     | 10.9                    | 0.62               | 20                               | 17.2          | 10.8            |
| 1      | 0.0                      | 0.0                     | 0.82               | 8                                | 0.2           | 0.0             |
| 1      | 8.9                      | 2.4                     | 0.00               | 74                               | 19.4          | 14.5            |

3. Improvement plan

3.1. Improving signal timing

In the design of signal timing scheme for intersections, the conversion coefficients of straight, right and left turn of convert coefficient are 1.67, 1.82 and 2.67, respectively[6]. Among them, standard car = Passenger car + bus * conversion coefficient, the formula for calculating saturated flow is

$$S = \frac{3600}{\sum h/n}$$

(1)

Where S is saturated flow, PCU / h; h is headway time; n is the number of data[7]. The data obtained through the calculation of the formula, as shown in the table below.

Table 4. Road traffic flow analysis

| Entrance   | Traffic flow | Traffic flow (pcu/h) |
|------------|--------------|----------------------|
|            | Passenger car | Bus                  | Standard car | Headway time | Saturated flow |
| North      | Go straight  | 708                  | 120          | 908          | 2.63          | 4370          |
|            | turn left    | 414                  | 48           | 542          | 2.71          | 2657          |
|            | turn right   | 521                  | 72           | 652          | 2.52          | 2857          |
| South      | Go straight  | 1014                 | 138          | 1244         | 2.46          | 5896          |
|            | turn left    | 384                  | 12           | 416          | 2.42          | 2975          |
|            | turn right   | 138                  | 48           | 225          | 2.36          | 1902          |
| East       | Go straight  | 408                  | 12           | 428          | 2.35          | 2932          |
|            | turn left    | 168                  | 12           | 200          | 2.32          | 2328          |
|            | turn right   | 336                  | 36           | 401          | 2.2           | 2920          |
| West       | Go straight  | 816                  | 12           | 836          | 2.2           | 4090          |
|            | turn left    | 120                  | 12           | 152          | 2.15          | 1675          |
|            | turn right   | 540                  | 60           | 649          | 2.1           | 3241          |

According to the road traffic flow and saturated traffic flow, the traffic flow ratio can be calculated as follows[8].
North import straight:

\[ y_{ns} = \frac{q_{ns}}{s_{ns}} = \frac{908}{4370} = 0.208 \]  
\[ (2) \]

Turn left at North import:

\[ y_{nl} = \frac{q_{nl}}{s_{nl}} = \frac{542}{2657} = 0.204 \]  
\[ (3) \]

Turn right at North Import:

\[ y_{nr} = \frac{q_{nr}}{s_{nr}} = \frac{652}{3250} = 0.201 \]  
\[ (4) \]

South import straight:

\[ y_{ss} = \frac{q_{ss}}{s_{ss}} = \frac{1244}{5896} = 0.211 \]  
\[ (5) \]

South import left turn:

\[ y_{sl} = \frac{q_{sl}}{s_{sl}} = \frac{416}{2975} = 0.140 \]  
\[ (6) \]

South import right turn:

\[ y_{sr} = \frac{q_{sr}}{s_{sr}} = \frac{225}{1902} = 0.118 \]  
\[ (7) \]

East import straight:

\[ y_{es} = \frac{q_{es}}{s_{es}} = \frac{428}{2932} = 0.146 \]  
\[ (8) \]

East import left turn:

\[ y_{el} = \frac{q_{el}}{s_{el}} = \frac{200}{2328} = 0.086 \]  
\[ (9) \]

East import right turn:

\[ y_{er} = \frac{q_{er}}{s_{er}} = \frac{401}{2920} = 0.137 \]  
\[ (10) \]

West import straight:

\[ y_{ws} = \frac{q_{ws}}{s_{ws}} = \frac{839}{4090} = 0.205 \]  
\[ (11) \]

West import left turn:

\[ y_{wl} = \frac{q_{wl}}{s_{wl}} = \frac{152}{1675} = 0.09 \]  
\[ (12) \]

West import right turn:

\[ y_{wr} = \frac{q_{wr}}{s_{wr}} = \frac{649}{2571} = 0.200 \]  
\[ (13) \]

Among them, \( q \) is the flow at the corresponding outlet and \( S \) is the saturated flow at the corresponding outlet[9]. It can be seen from the results calculated above that the key traffic flow is the north import straight line, the south import straight line, the north import right turn, and the west import straight line. Then, the total flow ratio is

\[ Y = y_{ns} + y_{ss} + y_{ns} + y_{es} = 0.208 + 0.201 + 0.211 + 0.146 = 0.766 \]  
\[ (14) \]

The Optimum Period is calculated by using Webster's best signal period formula. Among them,
yellow light time and all-red time can be taken for 3S and 2S respectively. From this calculation, it can be concluded that
\[
C = \frac{1.5l + 5}{1 - \sum_y} = \frac{1.5 \times 20 + 5}{1 - 0.825} = 149.6s
\]
(15)

Therefore, we can take the period length of 160s, through which we can calculate the effective green light time of each phase.

**Effective Green Time for West straight line:**
\[
t = (c - 1) \frac{Y_{as}}{Y} = 38s
\]
(16)

**Effective green time for South straight line:**
\[
t = (c - 1) \frac{Y_{as}}{Y} = 37s
\]
(17)

**Effective green time for North straight line:**
\[
t = (c - 1) \frac{Y_{as}}{Y} = 39s
\]
(18)

**Effective Green Time for East straight line:**
\[
t = (c - 1) \frac{Y_{as}}{Y} = 27s
\]
(19)

Since the walking time of pedestrians cannot be less than 25s, the cycle length is 170s. Then the optimized timing scheme is shown in the table.

**Table 5. Optimized signal timing**

| phase          | The first phase | The second phase | The third phase | The fourth phase |
|----------------|----------------|-----------------|----------------|-----------------|
| Green time /s  | 38             | 37              | 39             | 27              |
| Yellow light time /s | 5   | 5               | 5              | 5               |
| Signal loss time /s | 3   | 3               | 3              | 3               |

3.2. **Simulation results of improved Vissim**

When the signal is reconfigured according to the Webster method above, the obtained new signal is timed and simulated by vissim, and the following simulation results are obtained.

**Table 6. results of improved vissim simulation**

| node | Maximum queue length /s | Average queue length /s | parking times /time | Number of passing vehicles /Vehicle | delay time /s | parking time /s |
|------|-------------------------|-------------------------|---------------------|-------------------------------------|---------------|----------------|
| 1    | 80.6                    | 25.7                    | 0.61                | 25                                  | 11.2          | 12.0           |
| 1    | 61.6                    | 18.6                    | 1.23                | 24                                  | 30.5          | 31.5           |
| 1    | 80.6                    | 18.6                    | 0.60                | 164                                 | 20.5          | 9.5            |
| 1    | 71.8                    | 25.6                    | 0.34                | 8                                   | 6             | 0.0            |
| 1    | 50.5                    | 8.6                     | 0.44                | 103                                 | 10.6          | 8.7            |
| 1    | 50.5                    | 8.6                     | 0.59                | 15                                  | 22.6          | 33.2           |
| 1    | 30.6                    | 4.3                     | 0.40                | 25                                  | 13.4          | 6.7            |
| 1    | 0.0                     | 0.0                     | 0.35                | 24                                  | 0.1           | 0.0            |
| 1    | 3.5                     | 0.3                     | 0.00                | 88                                  | 8.4           | 9.6            |

4. **Analysis and comparison of simulation results before and after signal timing optimization**

The simulation results before and after the signal timing improvement are made into a line chart, so that the differences can be seen more intuitively.
Figure 2. Comparison of maximum queue length results before and after improvement

Figure 3. Comparison of the delays before and after improvement

Figure 4. Comparison of parking time before and after improvement

Figure 5. Comparison of the results of average queue length before and after improvement

Figure 6. Comparison of parking times before and after improvement

Figure 7. Comparison of the number of vehicles passing through before and after improvement
Based on the above comparison results, it can be seen that after the improvement of Webster timing method, the average vehicle delay is reduced by 25.24%, and the parking time is reduced by 35.16%. The maximum queue length, average queue length and parking times also decreased, while the number of passing vehicles increased. Especially, the delay of vehicles has been improved obviously. This improves the capacity of the intersection at North Street and improves the service level at the intersection.

5. Conclusion
This paper puts forward a way to improve the traffic congestion at intersections by Webster timing method. After the simulation of vissim, it is concluded that vehicle delay, parking times, parking time and queue length have been improved. This paper provides a reference value for improving the capacity of intersections and urban traffic congestion.

Reference
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