Optimal design of transportation signal control at the intersection based on Webster signal timing method

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Abstract. Urban transportation congestion has become a common phenomenon in the morning and evening peak. As the key node of urban transportation, optimizing the signal timing scheme of intersections is an effective measure to improve its traffic efficiency. In this paper, Webster’s signal timing method is used to optimize the signal timing scheme of intersection, and then VISSIM software is used to simulate the two schemes, and the queue length, parking times, travel time, delay time and pollution emission of each entrance at the intersection are optimized and analyzed. After optimization, the traffic condition of the intersection is obviously improved.

1. Introduction
Transportation is the foundation of other urban activities. With the rapid development of China’s social economy, the number of motor vehicles keeps increasing rapidly. At present, all parts of the country are generally faced with serious traffic congestion, which not only causes huge economic losses, but also causes great pollution to the environment. Traffic congestion also has a great impact on the ecological environment, including traffic noise, greenhouse effect and air pollution.

Facts show that improving traffic supply by building new roads is not an effective way to alleviate traffic congestion. A large number of studies at home and abroad show that one of the important ways to alleviate urban traffic problems is to effectively improve the level of traffic management and control. As the basic unit of urban traffic control, the control strategy of signalized intersection is of great significance to solve traffic problems. Reasonable signal timing at intersections can greatly improve the operation efficiency of vehicles at intersections[1], not only greatly improve the traffic capacity of intersections, but also alleviate traffic congestion and reduce delays to a certain extent.

2. Ease of Use
Traffic timing is optimized by Webster method, and the signal timing scheme is obtained, which is then simulated by VISSIM software. By comparing the indexes of each intersection before and after the optimization, the queue length and delay time of each entrance of the intersection are reduced, and the carbon emission within the intersection under signal control is analyzed as the evaluation standard.
2.1. **Webster Signal timing method**

This method is based on Webster's estimation of vehicle delay at intersections, and determines a series of corresponding timing parameters by optimizing the cycle length. Webster's method, including related principles, steps and algorithms, is a classical method for calculating intersection signal timing.

Webster model is a method to calculate signal timing aiming at minimizing vehicle delay time, so its core content is the calculation of vehicle delay and optimal cycle time.

Its delay formula is obtained by calibrating random delay and average delay by Monte Carlo simulation method, such as the following formula:

\[
d = \frac{C(1 - \frac{E}{c})^2}{2(1 - \frac{q}{s})} + \frac{x^2}{2q(1 - x)} - 0.65(C \frac{1}{q^3}) \cdot 2 + \frac{(E)}{c}
\]

In order to get the best cycle time to minimize the total delay of intersection, the best cycle time can be obtained by taking the partial derivative of the total delay to cycle time and making the partial derivative equal to 0.

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

The model well reflects the quantitative relationship between vehicle delay and signal timing, traffic volume and saturation at intersections with low saturation.

The calculation formulas of basic timing parameters, such as green signal ratio, flow ratio, loss time and effective green light time of each phase, of various timing models are the same, only the cycle duration, and the calculation formulas of delay will be different due to different application ranges [2].

2.2. **Design of signal timing scheme**

In the timing design of traffic signals at a single intersection, signal timing periods should be divided according to different traffic periods, and corresponding timing schemes should be determined in the same period. The main goal of point control is to minimize vehicle delay and stopping times, which is the most basic form of signal control [3]. Webster method is the basis of other timing signal timing methods, this paper also uses this method to calculate and explain the timing scheme of single-point signal control at road intersections.

2.3. **Calculation and analysis of basic data of intersection**

2.3.1. **Geometric parameters of intersection entrance road**

Figure.1 Intersection plan
Table.1  Geometric parameters of each inlet channel

| Direction of entrance road | Number of lanes | Straight right lanes | Turn left lane | Lane width/m |
|----------------------------|-----------------|----------------------|----------------|--------------|
| South entrance             | 2               | 1                    | 1              | 3.5          |
| North entrance             | 2               | 1                    | 1              | 3.5          |
| East entrance              | 3               | 2                    | 1              | 3.5          |
| West entrance              | 3               | 2                    | 1              | 3.5          |

2.3.2. Traffic volume of each entrance at intersection

Taking the traffic flow in the morning rush hour of the intersection as the representative peak hour traffic volume, the traffic flow of each entrance is obtained by analyzing and sorting out the traffic survey data of the intersection, and the results are shown in the following table:

Table.2  Traffic statistics results

| Entrance road | Direction  | Volume of traffic (pcu/h) | Sum (pcu/h) |
|--------------|------------|---------------------------|-------------|
| South entrance | Straight right | 95                       | 186         |
|               | Left       | 91                        |             |
| North entrance | Straight right | 231                      | 330         |
|               | Left       | 99                        |             |
| East entrance | Right      | 56                        | 446         |
|               | Left       | 88                        |             |
|               | Straight   | 302                       |             |
| West entrance | Right      | 124                       | 570         |
|               | Left       | 149                       |             |
|               | Straight   | 297                       |             |

2.3.3. Signal Timing of Intersection Status

The actual signal timing at the intersection is a four-phase scheme with a period of 84s. At each phase, the green light display time is 18s, the yellow light display time is 3s, the starting loss time is 3s too.

2.4. Saturated flow of each inlet channel

Table.3  Saturated flow at north and south entrances

| Direction of entrance road | South entrance (pcu/h) | North entrance (pcu/h) |
|----------------------------|------------------------|------------------------|
| Straight right lane        | 1309                   | 1267                   |
| Turn left lane             | 1396                   | 1403                   |

Table.4  Saturated flow of at east and west entrances

| Direction of entrance road | East entrance (pcu/h) | West entrance (pcu/h) |
|----------------------------|-----------------------|-----------------------|
| Through lane               | 1614                  | 1643                  |
| Turn left lane             | 1400                  | 1412                  |
| Turn right lane            | 1558                  | 1481                  |
2.5. **Design timing results**

The main purpose of traffic signal phase is to properly separate traffic flows that conflict with each other or interfere seriously, and reduce traffic conflicts and interference at intersections.

![Design traffic signal timing chart](image)

According to the relevant calculation, the signal timing scheme of the intersection design can be obtained as follows: the duration of each cycle is 69s. In which the green time of the first phase is 12s; the green time of the second phase, the third phase and the fourth phase is 15s, and the yellow time of each phase is 3s. The starting loss time is 3s.

Because the actual situation of the intersection is basically no pedestrians and non-motor vehicles, and the traffic volume at the south entrance is less than the other three entrances, it is feasible to set the green light time of 12s for the signal lights at the south entrance.

### 3. Results and analysis

#### 3.1. **Traffic capacity optimization results**

|                | Existing timing | Design timing |
|----------------|-----------------|---------------|
| South entrance | 578             | 470           |
| North entrance | 571             | 580           |
| East entrance  | 978             | 993           |
| West entrance  | 970             | 986           |
| Intersection   | 3097            | 3029          |

It can be seen from the above table that the traffic capacity of the other three entrances except the south entrance has been improved to varying degrees, and it is also feasible for the south entrance to slightly reduce its traffic capacity because of its small traffic volume, and the traffic capacity level of the whole intersection is basically balanced.

#### 3.2. **Service level optimization results**

| Entrance road | Existing delays (s) | Service level |
|---------------|---------------------|---------------|
| South entrance | 28.5                | C             |
| North entrance | 19.6                | B             |
| East entrance  | 22.6                | C             |
| West entrance  | 20.6                | C             |
| Intersection   | 21.9                | C             |
Table.7  Design intersection service level

| Entrance road   | Existing delays (s) | Service level |
|-----------------|---------------------|---------------|
| South entrance  | 23.3                | C             |
| North entrance  | 12.5                | B             |
| East entrance   | 19.5                | B             |
| West entrance   | 18.4                | B             |
| Intersection    | 17.3                | B             |

It can be seen from the above two tables that the service level of intersections has changed obviously, from the original almost all-C service level of each entrance road to almost all-B service level, and the whole intersection service level has also changed from C level to B level.

3.3. VISSIM simulation analysis

According to VISSIM simulation evaluation results and output files, we can analyze the simulation evaluation results and study the influence of changing the signal timing scheme of signal lights on intersections.

Table.8  Comparison of different index schemes

| Evaluation index | Existing scheme | Optimization scheme |
|------------------|-----------------|---------------------|
| Average queue length/m | 4.33            | 3.32                |
| Maximum queue length/m | 22.75           | 21.58               |
| Number of stops/f    | 12.25           | 12.04               |
| travel time/s        | 29.16           | 27.36               |
| Delay time/s         | 17.08           | 15.24               |

It can be seen from the above table that the maximum queue length is reduced from 22.75m to 21.58m, a decrease of 5.1%. Parking times decreased from 12.25 times to 12.04 times, a decrease of 1.7%. The vehicle delay time was reduced from 17.08s to 15.24s, a decrease of 10.8%.

Figure.4  Pollution emission comparison chart

It can be seen from the above figure that the emissions of VOC, CO and NOX have all been reduced by a part, and all three have reduced their emissions by 8%.

Using VISSIM software, traffic simulation is carried out for the current scheme and the optimized design scheme of intersection respectively. According to the output documents, comparative analysis is made. By comparing the queue length, parking times, travel time, delay time and pollution emission, it can be seen that the optimized design scheme is superior to the current scheme in all aspects.
4. Conclusion
When optimizing the design of signal timing at intersections, the change of traffic flow at intersections should be considered, which can be controlled in different periods. If necessary, inductive signal timing can be adopted, and the traffic volume will change with time, land use and other factors. Therefore, we need to modify and improve the signal timing at intersections according to specific conditions.

The traffic volume of many sections in the central ring of the university town is not large, so it is necessary to set the signal timing without setting signal lights or only considering the traffic volume during peak hours, or to use inductive signals. Since the traffic volume in the north-south direction of this intersection is relatively small, it is possible to set up only the signal lights flashing yellow during off-peak hours, obey the traffic flow in the east-west direction to drive consciously, look for gap traffic, and calculate and optimize the timing of signal lights according to the corresponding traffic volume during peak hours for management.

In this paper, the intersection of Zhonghuan East Road and Guang Mei West Road is taken as the research object, and the traffic control scheme is optimized by Webster method according to the intersection data obtained from the actual investigation. Comparing the signal timing schemes before and after optimization with VISSIM simulation software, it can be seen that the queue length, parking times, travel time, delay time and pollutant emission of the optimized intersection are obviously reduced, the actual delay of intersection is reduced from 21.9s to 17.3s, the service level of intersections has risen from C level to B level, and the traffic efficiency of vehicles has been significantly improved.

According to the actual situation of vehicles passing through intersections, the signal timing analysis of intersections can not only greatly improve the traffic capacity of intersections, but also alleviate urban traffic congestion, reduce delays and improve the travel efficiency of residents to a certain extent.

References
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