Optimization design of Transportation signal timing based on numerical solution method

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Abstract. In this paper, the improved numerical method is used to time the traffic lights at intersections. The traditional numerical solution method cannot make the setting of phase difference the most reasonable, and the actual distance of each intersection cannot completely meet the ideal distance, resulting in a lot of loss of green time. Therefore, this method still needs to be improved. Although the survey data in this paper are obtained through field investigation, they are still not universal. More accurate data come from multiple surveys and integration.

1. INTRODUCTION
In today’s urban road planning, an important means of trunk road traffic signal control is based on the length of the road to control the traffic signals at several intersections on the main road, the vehicle speed and each intersection of the single point signal control scheme. So as to minimize delays. This can improve the capacity of main traffic, realize the fast and safe operation of traffic flow, reduce delay, and create a good urban traffic environment effect.

The simple green wave coordinated control signal timing methods introduced in the traffic Engineering Manual in 1998, namely the numerical solution method and the graphic method, are the most widely used methods. On this basis, many domestic scholars put forward and improved many models according to different analysis angles. Zhu Wenxing (2005) regarded the delay of major vehicles as two parts: queuing delay and vehicle departure delay, so as to establish the phase difference optimization model and optimize the objective function with genetic algorithm [1].Zang Li Lin (2007) established a dynamic model of trunk line traffic, and solved it by using an improved genetic algorithm to realize the hierarchical control of the trunk line system [2].Shen Guojiang (2008) proposed a two-way green wave trunk line traffic dynamic coordination control strategy based on multi-Agent distributed control; Shen Guojiang et al. (2010) proposed a new trunk coordinated control technology using coordination layer and control layer, and combined fuzzy control and neural network to solve the model [3].Lv Bin et al. (2011) adopted the information difference entropy theory and multi-attribute comprehensive decision making method to design the phase difference optimization algorithm for the line control system, and adopted travel time, vehicle delay and queue length as evaluation indexes [4].

2. Current situation and analysis
Distribution based on the intersection with traffic coordination control theory as the foundation, combined with the feature of Ren Min road traffic trunk line transportation, according to the time line type control system, the design method of the select signal phase scheme, design of intersection signal timing scheme, choose the key period, to improve the vehicle speed, reduce through the road travel time.
2.1. Intersection status
Ren Min Road is the junction between the new city and the old city, Dennis shopping mall has attracted an additional volume of traffic. Due to the old road has been unable to meet the specific requirements of traffic flow, People’s Road recently had a renovation. Widened the road width, added bus lane and other traffic facilities.

The geometric shape of the intersection of Ren Min Road and Ta Nan Road: the intersection is a cross intersection, with a very wide road width and a wide green belt in the middle of the section. The East – West entrance and exit lanes are provided with bus lanes. There are small middle road safety islands and large pedestrian crossing safety islands. The situation of the intersection is as follows:

![Image of the intersection](image)

2.2. Traffic analysis
Through field observation and investigation, the traffic problems of the section of Ren Min Road trunk road from Ta Nan Road are mainly manifested in the following two aspects:

The distribution of motor vehicle trips is not reasonable, which is concentrated in a few sections and intersections, so the delay of vehicles and the queue length of intersections increase.

The signal cycle time and phase timing of each intersection are unreasonable, frequent congestion occurs in peak hours, and vehicle delays are relatively large.

Generally, the service level of signalized intersections is measured and evaluated by delay. In order to intuitively measure the service level of optimized road intersections, the service level standard provided in the US road Capacity Manual [5] is adopted.

Combined with the characteristics of relatively large saturation of the intersection studied in this paper, the specific delay analysis is as follows:

![Image of parking delay meter](image)

Table 1. Entrance flow at flat peak intersection

| Inlet direction | East | West | South | North | total |
|-----------------|------|------|-------|-------|-------|
| Flat peak flow  | 835  | 789  | 771   | 711   | 3106  |
| Evening peak flow| 1054 | 1042 | 1543  | 1216  | 4855  |

Table 2. Parking delay meter at east exit of intersection of Ren Min Road and Ta Nan Road

| Inlet direction | East entrance | West entrance | South entrance | North entrance |
|-----------------|---------------|---------------|----------------|----------------|
| delay (s)       | 53            | 45            | 57             | 51             |
| The service level| D             | D             | E              | D              |
3. Signal timing scheme

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 traffic capacity of the road, the Webster method, the most classic in the world, is adopted here to time the intersection signals.

3.1. Selection of intersection signal phase

In the online control system, in order to ensure the system has sufficient bandwidth and to ensure sufficient coordination with each intersection, complex phase design is often not carried out. Through reasonable phase design, the phase design of the intersection within the research scope of Ren min Road is shown in the following table.

Table.3 The signal timing scheme at the intersection of Ren Min Road and Ta Nan Road

| Signal phase | The first phase | The second phase | The third phase | The fourth phase |
|--------------|----------------|-----------------|----------------|-----------------|
|              |                |                 |                |                 |

3.2. Intersection timing signal timing

3.2.1. Determine the design traffic volume

By measuring the flow rate of each inlet channel for 15 minutes, pass the formula:

\[ q = 4 \times Q_{15\text{min}} \]  

The available hourly traffic volume is shown in the table below:

Table.4 Measured traffic volume

| Inlet channel name     | 15min flow | 1h flow |
|------------------------|------------|--------|
|                        | Straight   | Turn left | Straight | Turn left |
| Ren Min Road East      | 207        | 72      | 828      | 288       |
| Ren Min Road West      | 214        | 86      | 896      | 344       |
| Ta Nan Road South      | 421        | 53      | 1684     | 212       |
| Ta Nan Road North      | 221        | 125     | 884      | 500       |

3.2.2. Determination of saturated flow

The \( S_{\text{bt}} \) of the basic saturation flow in the entrance lane going straight, turning left and turning right are the determined values, which are respectively 1650pcu/h, 1550pcu/h and 1550pcu/h.

3.2.2.1 Lane width correction

\[ f_w = \begin{cases} 
0.4(W - 0.5), & 2.7 \leq W \leq 3.0 \\
1, & 3.0 \leq W \leq 3.5 \\
0.05(W + 16.5), & W > 3.5 
\end{cases} \]  

Where: \( f_w \) — lane width correction coefficient; \( W \) — Lane width (m).
3.2.2.2 Slope and cart calibration

\[ f_g = 1 - (G + HV) \]  

Where: \( f_g \) — slope and calibration coefficient of cart; \( G \) — longitudinal slope of the road, when descending takes 0; \( HV \) —the ratio of cars, where HV is not greater than 0.50.

**Saturation flow in the straight going lane**

\[ S_f = S_{st} \times f_g \times f_b \]  

Where: \( S_f \) —saturation flow rate of straight lane (pcu/h); \( S_{st} \) —basic saturation flow rate of straight lane (pcu/h); \( f_b \) —The correction factor of bicycle influence, which is 1 here.

3.2.2.3 Saturation flow in the left-turn dedicated lane

For the intersection in this study, there are left-turn lanes for each direction, and there is a left-turn special phase for each direction.

When there is a special left turn phase, \( S_L = S_{hl} \times f_w \times f_g \)  

Where: \( S_L \) —Saturation flow rate (pcu/h) when the left-turn special lane has special phase; \( S_{hl} \) —Basic saturation flow (pcu/h) when the left lane has a dedicated phase.

Then the saturation flow of each inlet channel is shown in the following table:

| Inlet channel name      | straight (pcu/h) | Turn left (pcu/h) |
|-------------------------|-----------------|-------------------|
| Ren Min Road East       | 1518            | 1255              |
| Ren Min Road West       | 1448            | 1474              |
| Ta Nan Road South       | 1567            | 1481              |
| Ta Nan Road North       | 1578            | 1465              |

3.2.3. calculation of timing parameters

3.2.3.1 The duration of the signal cycle is calculated as follows:

\[ C = \frac{L}{1 - Y} \]  

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

3.2.3.2 The total signal loss time is calculated as follows:

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

Where: \( L_s \) — starting loss time(s), should be measured, without measured data, 3s can be taken; \( A \) —Length of yellow light(s), usually 3s; \( I \) —Interval between green light(s). \( K \) —the number of green light intervals in a cycle.

3.2.3.3 The interval between green lights is calculated by the following formula:

\[ I = \frac{z}{U_e} + t_s \]  

Where: \( z \) —Distance from the stop line to the conflict point(m); \( U_e \) —vehicle speed on the entrance lane(m/s); \( t_s \) —vehicle braking time(s).

When the green time interval \( I < 3 \text{s} \) is calculated, the yellow time is set as 3s.
3.2.3.4 The total flow ratio is calculated as follows:

$$Y = \sum_{j=1}^{n} \max \left( Y_j, Y', \ldots \right)$$

$$= \sum_{j=1}^{n} \max \left[ \frac{q_{dj}}{S_d}, \frac{q_{dj}}{S_d}, \ldots \right] \quad \left( Y \leq 0.9 \right)$$

(9)

Where: $J$ — phase number within a period; $Y$ — sum of the maximum flow ratio $y$ values of all signal phases constituting the period; $Y_j$ — the flow ratio of $j$ phase; $q_{dj}$ — Design traffic volume,(pcu/h); $S_d$ — Calibration for saturation flow(pcu/h).

When $Y > 0.9$ is calculated, it indicates that the inlet channel design is unreasonable, and it is required to improve the inlet channel design.

3.2.3.5 Total effective green time: The total effective green time per cycle is calculated as follows:

$$G_e = C - L$$

(10)

3.2.3.6 The effective green time of each phase is calculated as follows:

$$g_{sj} = G_e \cdot \frac{\max (Y_j, Y', \ldots)}{Y}$$

(11)

3.2.3.7 The green letter ratio of each phase is calculated as follows:

$$\lambda_j = \frac{g_{sj}}{C_o}$$

(12)

3.2.3.8 The actual display green time of each phase is calculated as follows:

$$g_j = g_{sj} - A_j + I_j$$

(13)

Where: $I_j$ — $j$ phase starting loss time; $A_j$ — $j$ phase yellow light time.

3.2.3.9 The minimum green time is calculated as follows:

$$g_{\text{min}} = 7 + \frac{L_p}{v_p} - I$$

(14)

Where: $L_p$ — the length of pedestrian crossing the street (m); $v_p$ — pedestrian crossing speed, usually 1.0m/s; $I$ — Interval between green lights(s).

If the calculated green time is less than the corresponding minimum green time, in order to enable pedestrians to safely cross the road, the length of the calculation cycle (to meet the minimum green time) should be extended and recalculated.

The cycle, timing parameters and the straight-line green ratio of the main road at different time periods of each intersection are calculated by this method, and the results are shown in the following table:

| Table 6 Signal timing scheme |
|-----------------------------|
| Interception name           | Duration of signal cycle | Phase timing/s | Main line green signal ratio/% |
|                             | /s                        | One   | Two | Three | Four |                     |
| Ren Min Road -Ta Nan Road   | Flat peak                 | 115    | 32  | 27    | 36   | 8                   | 28                  |
|                             | Evening peak              | 186    | 39  | 43    | 50   | 34                  | 20                  |
4. Conclusion
Single point signal control is the foundation of urban main road signal coordination control. Therefore, we need to set up the intersection reasonably, turn on the red and green lights according to a certain phase sequence, and calculate the signal timing of each intersection according to the traffic flow. If the signal timing design of a single intersection is not reasonable, it should be timely improved. By comparison, it can be seen that the optimized scheme has an ideal improvement compared with the current situation. It can reduce the delay of the intersection, reduce the congestion status of the intersection, enhance the traffic capacity of the intersection, and achieve significant optimization effect. The optimization scheme and related measures can provide effective reference for alleviating the current increasingly serious congestion status of urban roads.

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