Multi-junction traffic light optimization during holiday based on improved green wave band control

Mingyue Yin

1Information management and information system, Wuhan University of Technology, Wuhan City, Hubei Province, 430070, China

*yinmingyue9840@126.com

Abstract. In recent years, urban car ownership has increased with rapid economic development, and urban traffic congestion has become more and more serious. Especially during the holidays, the number of people traveling by car has increased, the pressure on traffic is greater, and the traditional traffic lights are fixed. Far from meeting the needs of the current road conditions. The traditional green wave control is improved, and the intelligent algorithm such as fuzzy algorithm and genetic algorithm is used to solve the green wave period and signal timing. Taking Wuhan as an example, using VISSIM to simulate, the results show that the method effectively reduces vehicle delay and average number of stops, and improves the fluency of urban multi-junction traffic.

1. Introduction

China's economy is developing at a rapid pace, and the number of car ownership is growing rapidly in the form of an index, which is far greater than the speed of urban traffic road construction[1]. People's lives are gradually becoming richer. People visiting relatives and friends during the holidays have significantly increased their number of self-driving travels, which has intensified the country. Traffic congestion in big cities. Traffic congestion will not only reduce travel speed, increase travel time costs, but also increase urban pollution and hinder urban development. The direct and effective way to solve the congestion problem is to rationally allocate the traffic light time of the traffic signal according to the real-time traffic flow at the intersection.

At present, most cities in China still adopt the traditional fixed time of traffic lights, and their time is not easy to adjust. In the case of large traffic irregularities such as holidays and traffic accidents, serious traffic jams will occur[2]; real-time traffic sensing The traffic light is controlled to switch the current phase green light according to the traffic condition detected by the intersection setting detector. According to statistics, this method is only applicable to the road segment with traffic saturation rate less than 80% and relatively high traffic flow randomness, and if other phases are continuous The traffic flow will increase the delay time of the vehicle[3]; the adaptive control traffic light mainly uses modern advanced algorithms, such as genetic algorithm and ant colony algorithm to implement optimal control of the signal light system[4]. The advanced system identification algorithm and the data collected by the sensor are used to identify the black box model of the traffic intersection[5], and then the latest data is substituted into the black box model to find the optimal solution, and then the corresponding signal is assigned to each phase according to the optimal solution. In this way, this method can adapt to complex dynamic traffic changes and achieve optimal use of resources.

Starting from the overall situation of the city, multi-junction signal lights are coordinated and optimized to reduce the probability of vehicles encountering red lights, and improve the traffic efficiency
of intersections as a whole. This paper focuses on the traffic light optimization scheme of urban multi-traffic intersections with the increase of holiday traffic flow, reducing the number of vehicles stranded at intersections and alleviating traffic pressure.

2. Holiday traffic situation
Taking the National Day Eleventh Golden Week in 2018 as an example, the peak congestion delay time during Chongqing holidays is 2.11, and the average speed is 21.61km/h. That is, Chongqing travels twice during the holidays to reach the destination. Other major cities, such as Beijing, Harbin, Guangzhou, Xi'an, Lanzhou, Wuhan, also face the same problems during the holidays. The specific data is shown in Table 1.

| City       | Congestion delay Maximum index | Average speed during the holidays(km/h) | Average annual speed(km/h) |
|------------|-------------------------------|----------------------------------------|----------------------------|
| Wuhan      | 1.73                          | 28.21                                  | 39.45                      |
| Beijing    | 1.91                          | 25.42                                  | 36.37                      |
| Xi’an      | 1.73                          | 24.72                                  | 29.31                      |
| Lanzhou    | 1.74                          | 23.06                                  | 28.98                      |
| Harbin     | 1.98                          | 21.23                                  | 29.81                      |
| Chongqing  | 2.11                          | 21.61                                  | 28.61                      |
| Guangzhou  | 1.88                          | 23.19                                  | 35.86                      |

*The data comes from the Amap big data report.*

Taking Wuhan as an example, during the 11th year of 2018, the average daily traffic congestion delay index of Wuhan City was 1.74, which was 11.55% higher than usual, and the average daily speed was 27.18km/h, which was 33.44% lower than usual. Among them, Wuhan Wuhan Avenue (north side of Second Ring Road), Luoshi Road, Shucheng Road, and Tazihu East Road, the congestion delay index averaged 5.98, and the lowest speed was Tazihu East Road, with an average of 6.75 km/h. Accumulated congestion for 26 hours in one period [6].

3. Multi-road traffic light model establishment

3.1 Intersection signal performance indicators
Average delay time: delay time refers to the difference between the ideal travel time and the actual travel time. It is the main indicator for evaluating the signal control effect. The shorter the delay time, the better the control effect of the signal light [7]. The average delay time is the average of all vehicle delay times, and it is easy to see the travel efficiency of a single vehicle from the average delay.

The number of stops: it refers to the average number of times the vehicle has reached the intersection and stopped from the standstill after the green light [8].

3.2 Green wave control optimization
The green wave band is incorporated into the computer control system for the traffic lights or the traffic lights in the traffic area, and the various intersections in the control system are coordinated, so that the vehicles traveling on the main road do not encounter red light or less red light. The green wave band dynamically adjusts the green light time and cycle time of each intersection and each phase by controlling the parameters of the intersection signal light, so that the vehicle can pass the intersection as smoothly as possible, reduce the number of stops and time delay, improve the traffic capacity of the road, and alleviate the traffic jam in the city.
In the four-phase control scheme shown in Fig. 1, after the vehicle passes through the intersection A, the traffic flow 1 is behind the 2, and the traffic is dispersed into three traffic flows at the intersection B. The traffic flow 2 has a small probability of turning left at the intersection B, and the two traffic flows are straight and right. The traditional green wave is only for traffic flow 1, and when it reaches intersection B, it just happens to encounter a green light. However, in the actual situation, there is still a traffic flow 3 waiting in front of the traffic flow 5, and after the traffic light turns into a green light, it takes a certain time for the traffic flow 3 to reach the speed of the green wave band from the stationary state, and the traffic flow 5 will be delayed, so it is bound to cause a large traffic flow to the green wave. Delays, which in turn affect the filtering control effects of multiple intersections. Based on the problems existing in traditional green wave control, we appropriately reduce the phase difference between the intersections. The new phase difference formula is

$$ t = \frac{s}{v} - nT - \Delta t. $$

(1)

### 3.3 Dynamic Green Wave Period Based on Fuzzy Algorithm

The common period of the traditional green wave control is fixed, and the maximum value of each intersection is usually taken, which will inevitably sacrifice the traffic efficiency of the intersection with a shorter period. The traffic volume varies greatly from holiday to holiday at different times. During peak hours and small public periods, the vehicle will be blocked on the outside of the green wave section. If the public period is large during the period of small traffic volume, the green light signal will be wasted. Therefore, for different time periods, different traffic volumes should use different common periods. In order to improve the traffic efficiency, the green wave signal period is matched with the real-time traffic flow, and the urban vehicle has nonlinearity and randomness. Therefore, the fuzzy algorithm is used to calculate and calculate the green wave period. Think of multiple intersections as a whole, and the traffic volume is the sum of the traffic flows on each lane of all intersections. Defining the traffic flow $q_{ij}(t)$ on the $j$ lane in the $i$ direction of the $t$ cycle is

$$ q_{ij}(t) = q_{ij}(t-1) + k(q_{ij}(t-1) - q_{ij}(t-2)). $$

(2)

Where $i = 1, 2, ..., m$ denotes the direction of each road, $j = 1, 2, 3$ denotes a left turn, a straight run and a right turn lane, respectively, $k$ is a proportional coefficient, and $0 < k < 1$. Then the total traffic volume in the $t$ cycle is

$$ q(t) = \sum_{i=1}^{m} \sum_{j=1}^{3} q_{ij}(t). $$

(3)
The traffic volume at the intersection has a great influence on the green wave period. Therefore, the estimated traffic volume + the latest periodic traffic volume difference is used to estimate the T value of the next green wave period. The process is as shown.

The green wave period, the estimated total traffic volume, and the latest two-cycle traffic volume difference are divided into five fuzzy subsets, respectively

\[ T^* = \{VS, S, M, L, VL\}; \]
\[ q^* = \{VS, S, M, B, VB\}; \]
\[ \Delta q^* = \{NB, N, Z, P, PB\}. \] (4)

After many experiments, the triangle function is selected as the membership function of each fuzzy subset of each input and output variable, as shown in Figure 2.

![Figure 2. Membership function.](image)

According to the fuzzy subset of the difference between the estimated traffic volume and the latest two-cycle traffic volume, the inference condition of if x is A and y is B then z is C is used to obtain the fuzzy rule base, and then the traffic volume and the latest two cycles are estimated. After the traffic volume difference is input to the controller, the fuzzy rule base is queried, and the fuzzy subset of the green wave period is obtained. The anti-fuzzification is performed according to the weighted average, and then the green wave period T is obtained by the coefficient transformation.

\[ T = T_{\text{min}} + k \left( \frac{\sum_{i=1}^{n} \mu(T_i^*) q_i^*}{\sum_{i=1}^{n} \mu(T_i^*)} \right). \] (5)

4. Signal Timing Based on Genetic Algorithm and Dynamic Green Wave Period

The traditional intersection signal light timing method is for a single intersection. When the multi-junction joint is used, the average vehicle delay of the total delay \( D(t) \) of the multi-way is the shortest \( \min D(t) \) is the objective function. Waiting queue is

\[ Q_{ijk}(t) = \min(\max(Q_{(i-1)jk}(t) + G_{ijk}(t) - L_{ijk}(t), 0), Q_{\text{limit}}). \] (6)

Where \( G_{ijk}(t) \). \( L_{ijk}(t) \), and \( Q_{\text{limit}} \) are respectively the new arrival vehicle, the departure vehicle, and the maximum waiting queue on the \( j \)-direction \( k \) lanes at the end of the \( i \)-phase of the \( t \) cycle

\[ L_{ijk}(t) = \min(t_{\nu}, Q_{(i-1)jk} + G_{ijk}(t)), \] (7)
Where \( t_i \) is the phase green time and \( \nu \) is the probability that the vehicle will leave the lane. One phase delay is

\[
d_{ijk}(t) = \max(0, Q_{i,j,k}(t) - L_{ijk}(t) + d_c(t) + d_i(t)),
\]

If \( Q_{i,j,k}(t) > L_{ijk}(t) \), Headway is \( \sigma \) seconds, \( \omega \) is the number of arriving vehicles, and \( \varepsilon \) is the number of vehicles leaving.

\[
d_c(t) = \sum_{\omega=1}^{G_{i,j,k}(t)} \left( t_i - \sigma \left( \frac{\omega - \frac{1}{2}}{2} \right) \right) = \frac{G_{i,j,k}(t)t_i}{2},
\]

\[
d_i(t) = \sum_{\varepsilon=1}^{L_{ijk}(t)} \frac{\varepsilon - 1}{s} = \frac{L_{ijk}(t)(L_{ijk}(t) - 1)}{2s}.
\]

If \( Q_{i,j,k}(t) < L_{ijk}(t) \),

\[
d_i(t) = \sum_{\omega=1}^{G_{i,j,k}(t)} \max(0, \frac{Q_{i,j,k}(t) + (\omega - 1)}{s}) - \left( \frac{\omega - \frac{1}{2}}{2} \right) G_{i,j,k}(t) + \sum_{\omega=1}^{G_{i,j,k}(t)} \left( t_i - \sigma \left( \frac{\omega - \frac{1}{2}}{2} \right) \right),
\]

\[
d_i(t) = \sum_{\varepsilon=1}^{L_{ijk}(t)} \frac{\varepsilon - 1}{s} = \frac{Q_{i,j,k}(t)(Q_{i,j,k}(t) - 1)}{2s}.
\]

If the phase lane is red, the vehicle delay is

\[
d_{ijk}(t) = d_i(t) + Q_{i,j,k} t_i^p, \text{the total delay is } D(t) = \sum d_{ijk}(t).
\]

Constraints: Each intersection has a public green period, and \( \eta \) is the number of intersections.

\[
T = \sum_{i=1}^{\eta} t_i, \text{if } 1, 2, \ldots, \text{According to statistics, in order to ensure the safety of pedestrians through the intersection, then } 60 \leq T \leq 120 \text{ and } 15 \leq t_i^p \leq T - 45.
\]

Finally, find the appropriate function by genetic algorithm. \( f = \alpha - \beta d(t) \).

5. Simulation results and analysis

Taking the traffic situation of Wuhan 11 as an example, this paper uses the VISSIM simulation platform developed by German PTV Company to comprehensively and effectively evaluate the traffic plan to simulate the test scenario. This simulation simplifies the operation and adopts the section of the lion section with the largest holiday congestion delay index. Figure 2 is simulated. The simulation basic parameter setting adopts four items, the total traffic volume is 300–1000, the expected speed is 40–50 km/h, the maximum period of the signal light is 120s, and the performance index adopts Travel Time and \( d(t) \).

![Figure 3. Detecting road segment simplified map.](image)
In the simulation process, the adjustment is not in accordance with the actual situation, and then the simulation is performed multiple times and the data is statistically calculated. From the data, the original scheme (the phase difference reduction is 0s) is not the best solution. When the detection segments 1 and 3 are reduced by 3 on the basis of the original phase difference, the delay time, the less parking time and the number of parking times and the higher average speed are detected, and the best effect of the detection section 2 appears on the basis of the original phase difference. Decrease by 9s.

| Detection section | Phase difference reduction/s | Delay time / s | Improve effect /% | Number of stops/time | Improve effect /% |
|-------------------|------------------------------|----------------|-------------------|----------------------|------------------|
| 1                 | 0                            | 14.3           | 9.79              | 0.34                 | 5.88             |
|                   | 3                            | 12.9           |                   | 0.32                 |                  |
|                   | 0                            | 23.5           | 12.34             | 0.38                 | 18.42            |
| 2                 | 9                            | 20.6           |                   | 0.31                 |                  |
|                   | 0                            | 18.2           | 7.69              | 0.19                 | 15.79            |
| 3                 | 3                            | 16.8           |                   | 0.16                 |                  |

The optimum phase difference reduction amount of each detection section is compared with the delay time and the number of parking times when the phase difference reduction amount is zero, and the result is shown in Table 2. It can be seen that, compared with the original scheme, the phase difference can be appropriately reduced, which can reduce the delay time of detection segments 1-3 by 9.79%, 12.34%, and 7.69%, respectively, and the number of parking times is reduced by 5.88%, 18.42%, and 15.79%, respectively. Therefore, the efficiency of the lion road is effectively improved, and the control effect of the traditional green wave band is improved.

6. Footnotes
This paper focuses on the improvement of traffic conditions in holiday cities, and improves the traditional green wave band, making it more suitable for the optimization of multi-road traffic lights. The fly in the ointment is dependent on historical data, and does not take into account the impact of road construction, traffic accidents and other events on traffic flow. However, the improvement of the holidays not only saves the capital investment of the intelligent road test equipment, but also effectively alleviates the urban holiday congestion.

References
[1] Li X W. (2012) Quantitative analysis of urban road traffic efficiency and its influencing factors. Beijing Jiaotong University.
[2] Chen D. (2011) Research on Simulation Optimization of Urban Traffic Signals. Wuhan University of Technology.
[3] Liu C J. (2018) Research on coordinated control of multi-road traffic signals based on Q learning. Nanjing University of Posts and Telecommunications.
[4] Zhao B. (2016) Research on Traffic Light Scheduling Method for Traffic Network Optimization of Whole Road Network. East China Normal University.
[5] Liao B, Wu B Z. (2011) Real-time control simulation design of urban road multi-road traffic signals. Computer Age,12:25-29.
[6] Wuhan Municipal Transportation Administration. (2018) One-week travel guide. http://jgj.wuhan.gov.cn/.
[7] Hu T. (2013) Research on coordinated control of green wave in urban traffic trunk line [D]. Shanghai Jiaotong University.
[8] Nasser R. Sabar, Le Minh Kieu, Edward Chung, Takahiro Tsubota, Paulo Eduardo Maciel de Almeida. (2017) A memetic algorithm for real world multi-intersection traffic signal optimisation problems. Engineering Applications of Artificial Intelligence, 2017, 63: 45-53.