Advances in Engineering Research, volume 70
International Conference on Advanced Materials Science and Civil Engineering (AMSCE 2017)

Multi-objective Signal Timing Model of Single Intersection Based on Genetic Algorithm

Zhuoqun Wang [1], Yufei Hou[1], Qin Luo [1,*], Min Yan [1] and Yiming Zhang[2]
[1] College of Urban Rail Transit, Shenzhen University, Nanhai Ave 3688, Shenzhen, Guangdong, P.R. China 518060
[2] College of Transportation Engineering, NO.4800 Caoan Road, Shanghai, P.R. China 201804
*Corresponding author

Abstract—**Intersection is an important component of the urban transport network. It is the main place where traffic congestion usually takes place. One of the key to solve urban transport problems is to organize the traffic in intersection reasonably and effectively.This paper learned the theory of signal control based on single intersection and then respectively set up different multi-objective optimization models according to high or low lane saturability.The paper aims to decrease the amount of vehicle delay and reduce the parking rate. The model is carried out through genetic algorithm based on Matlab. A case is shown that the methods of optimization models and genetic algorithm are effective and feasible.**

Keywords-single-intersection; signal timing; genetic algorithm; Matlab

I. INTRODUCTION

Intersection is a main component of urban transport network and also the place where has high incidence on traffic accidents. One of the way to solve above problems is optimizing the rule of signal timing. At present, most of intersections use fixed timing, that easily lead to demand dissatisfaction or waste time under the traffic flow changes a lot in a day or other extreme situations. Therefore, how to make full use of existing facilities has become the key to solve the congestion problem, especially when the urban road infrastructure is becoming more and more perfect.

Li Xiaona[1] proposes to meet the different needs of multiple traffic signal timing model, according to the traffic flow at the intersection of different performance indicators. Yan Li[2] et al propose a multi-objective optimization algorithm for improving the efficiency of traffic signal control. Throughput maximum and average queue ratio minimum are selected as the optimization objectives of the traffic signal control under oversaturated condition. Liu Jinming[3] proposes the multi-objective programming signal timing model of fuzzy compromise programming, and take the total delay, the number of stops and the capacity of traffic at intersections as indexs. ZHAO Wen-xiu[4] et al designs the traditional timing, classical fuzzy control and simulation of vehicles average time delay after genetic algorithms are optimized. Araghi.S[5] et al have a review on comparison between computational intelligence methods and fixed-time method for controlling traffic signal timing. It focus on Q-learning, neural network, and fuzzy logic system. This paper shows the intelligent controllers have higher performance compared to the fixed-time controller. Xiaoke Zhou[6] et al think traffic problems often occur due to the traffic demands by the outnumbered vehicles on road. Maximizing traffic flow and minimizing the average waiting time are the goals of intelligent traffic control.

Intersection signal control program is effective or not, directly related to the entire transport system operating efficiency. Considering a variety of complex traffic conditions in a whole day at the intersection, the paper research on optimizing timing rules of single intersection and set up different multi-objective optimization models according to high or low lane saturability.The paper aims to easing urban road congestion by making intersection operation efficiency and safety.

II. MULTI-OBJECTIVE SIGNAL TIMING MODEL

Currently, most of timing rules are based on Webster and we found that it's not satisfactory when the intersection has higher saturation .Considering above problems, the paper proposed a multi-objective signal timing method, which is different for low flow ratio ($Y<0.75$) and high flow ratio ($0.75 \leqslant Y<0.95$).The goal is to reduce the intersection delay factor, reduce the parking rate, increase effective vehicle throughput at the unit time.

A. Low Flow Ratio Timing Model

In general, the other conditions remain unchanged, the greater the signal cycle, the greater the capacity, but at the same time delay and parking rate also increases, especially when the intersection traffic is relatively small, too large capacity has no actual significance. Therefore, under this case, this paper chose the delay factor and the parking rate as the optimization goal to optimize.

In the condition of low flow ratio, different delay calculation methods all have good adaptability, so the choice is free, but this paper in order to be consistent with the calculation method under the high flow ratio, chose HCM method to calculate. The expression is as follows:

$$\mathrm{d}=0.38c\frac{(1-\lambda)^2}{1-\lambda X}+173X^2\left[(X-1)+\sqrt{(X-1)^2+\frac{16X}{S}}\right] \quad (1)$$

d—average delay per vehicle;

C—cycle time;

λ—split;

q—standard traffic volume;

S—saturated flow;

X—Saturation, that is the ratio of maximum flow to lane capacity, $X = \frac{q}{\lambda S}$;

For the parking rate, we use the Webster model for calculation.

$$h = \frac{(1-\lambda)}{(1-y)} \quad (2)$$

λ—split;

y—flow ratio, $y = \frac{q}{s}$

According to the HCM delay formula, the average delay of the *i*th phase can be expressed as:

$$d_i = 0.38c\frac{(1-\lambda_i)^2}{1-\lambda_i X_i} + 173X_i^2[(X_i - 1) + \sqrt{(X_i - 1)^2 + \frac{16X_i}{S_i}}] \quad (3)$$

According to Webster model, the *i*th phase parking rate can be expressed as:

$$h_i = \frac{(1-\lambda_i)}{(1-y_i)} \quad (4)$$

Note: each symbol has the same meaning as above

We assign them different weighting coefficients, K_i^1, K_i^2, among them, $K_i^1 = S_I y_i K_i^2 = S_I y_i \cdot C$

$S_I y_i$ denote the total flow of the lane, K_i^2 means the delay time per parking time increases with the increase of the cycle time.

Then the objective function can be expressed as:

$$\min Z(C, g_1, g_2, \dots, g_n) = \sum_{i=1}^{n}(K_i^1 d_i + K_i^2 h_i) \quad (5)$$

Subject to:

$$g_{min} \le g_i \le g_{max} \quad (6)$$

$$C = \sum(g_i + l_i) \quad (7)$$

$$C_{min} \le C \le C_{max}, i \ge 0 \quad (8)$$

In the model, q_i, l_i, S_i are the input variables, and g_i, C are the output variables, that is, the desired variable.

B. High Flow Ratio Timing Model

Increasing capacity has become an urgent need in the context of high flows, but it has been noted that capacity and delay are negatively correlated, shows in the longer cycles, greater capacity, and the greater delays. When the cycle length increases to a certain value, its capacity is close to the design capacity of the intersection, but at this moment continue to increase the cycle length, capacity growth is more slowly, and the delay has increased dramatically.

In order to avoid this situation, the paper selected capacity and delay factors as the optimization goal, because the two are bound to each other, the optimal solution can be obtained.by coordinating the relationship between the two.

1) The choice of calculation methods.

The delay is calculated using the HCM method, which can be used when the saturation is smaller than 1.2. We thought the saturation is smaller than 1, although we discussed here is the high flow case. So we can use the formula for the calculation based on above conditions. For the capacity, use the formula to calculate.

2) The establishment of the objective function.

Since it is difficult to determine the weight relationship between traffic capacity and delay, it is not appropriate to build a model using linear relationships. Therefore, we used multiplication and division, the objective function is as follows:

$$\min Z(C, g_1, g_2, \dots, g_n) = \frac{\sum q_i d_i}{k \sum Q_i} \quad (9)$$

Subject to:

$$g_{min} \le g_i \le g_{max} \quad (10)$$

$$C = \sum(g_i + l_i) \quad (11)$$

$$C_{min} \le C \le C_{max} \quad (12)$$

where, k is a coefficient that we could adjust the value of k to make the value of delay is smaller than the capacity. K is desirable to be 1000. When the traffic capacity increases faster than the speed of delay increases, the function tends to optimize.

III. Solving Algorithm of Single-Point Timing Model

A. Model Solving Based on Genetic Algorithm

Based on the MATLAB platform, this paper solved the signal timing model of the single intersection by writing the corresponding m file as the fitness function of the genetic algorithm. As shown in Figure 1, we assume that the intersection signal phase plan is fixed and the channelization scheme is known.

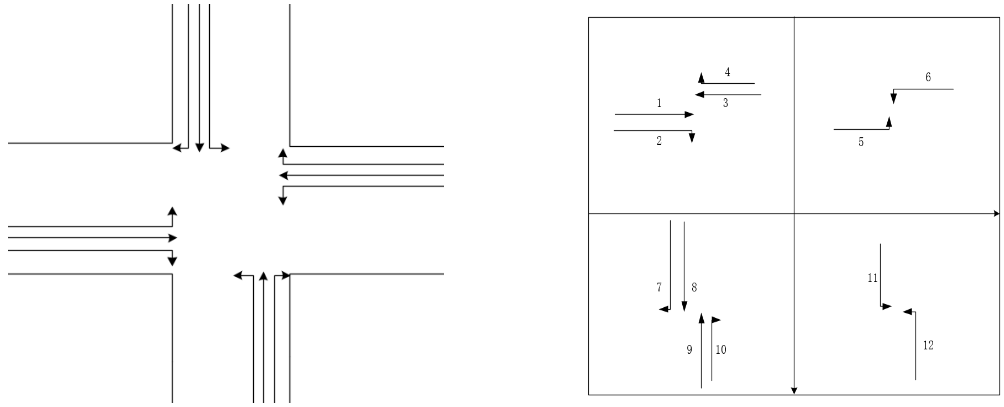

FIGURE I. PHASE SCHEME AND CHANNELIZATION SCHEME

An example is given for the simulation calculation. The saturated flow and actual flow rate of each lane are assumed to be known. The saturation flow of the straight lane and the right lane is 1600, the left lane is 1200, the ratios of each lane flow in phase from left to right, from top to bottom are as follows: y(1)=0.25; y(2)=0.23; y(3)=0.24; y(4)=0.26; y(5)=0.21; y(6)=0.17; y(7)=0. 38; y(8)=0.39; y(9)=0.36; y(10)=0.36; y(11)=0.09; y(12)=0.10. The yellow light time is 3s, and that is equal to the start loss time, then the actual green time of each phase is the effective green time. Taking the green time of each phase as the input and the comprehensive performance index D as the function output value, different optimization models were used to calculate the different flow rate.

Using genetic algorithm to slove the model,following is the chosen parameters.The number of variables is chosen to be 4 and the linear constraint is defined as "x (1) + x (2) + x (3) + x (4) <188"(the yellow light time is 3s, and the pre-loss is equal to post-compensation), the variable value is defined as "$20 \leq x_i \leq 80$", the mating probability is 0.8, the mutation probability is 0.2, the population size is 20, and the operation is stopped when there is no evolution over 50 generations.

From the results, we can see that the function stops computing after 297 generations. The final results are as follows: x (1) = 23.39, x (2) = 16.24, x (3) = 35.92, x (4) = 15.00. Because each phase green time is an integer, this group of data need to be further rounded operation.

IV. VALIDATION AND EVALUATION

In this paper, five sets of data are used for calculation. The selection of each lane flow ratio are shown in Table 1 according to the phase and channelization scheme shown in Fig.1.

As Table 2 shown are the results by comparing the multi-objective optimization method proposed in this paper with the Webster timing method .

TABLE I. THE TRAFFIC RATIO OF EACH LANE

Sample number / Lane Number	1	2	3	4	5
1	0.23	0.29	0.17	0.31	0.12
2	0.14	0.14	0.23	0.14	0.15
3	0.13	0.22	0.3	0.13	0.07
4	0.18	0.17	0.21	0.28	0.29
5	0.09	0.12	0.11	0.06	0.17
6	0.15	0.13	0.09	0.14	0.14
7	0.24	0.21	0.19	0.23	0.32
8	0.15	0.19	0.18	0.14	0.09
9	0.20	0.18	0.20	0.19	0.16
10	0.17	0.19	0.21	0.09	0.21
11	0.07	0.05	0.08	0.12	0.11
12	0.05	0.06	0.09	0.05	0.07

TABLE II. COMPARISON AND EVALUATION OF SINGLE-POINT TIMING

Sample number / Index	1	2	3	4	5
Webster total delays	69089	83880	89096	87855	15544
Webster total parking times	2536.9	2787.2	2941.7	2576.2	2539.9
Webster total capacity	4028.9	4111.6	4188.8	4552.2	4850.2
Optimization algorithm total delays	69415	74648	85605	83298	11170
Optimization algorithm total parking times	2602.1	2574.4	2905.4	2584.2	2578.3
Optimization algorithm total capacity	4084.7	4260.9	4306.4	4507.7	4675

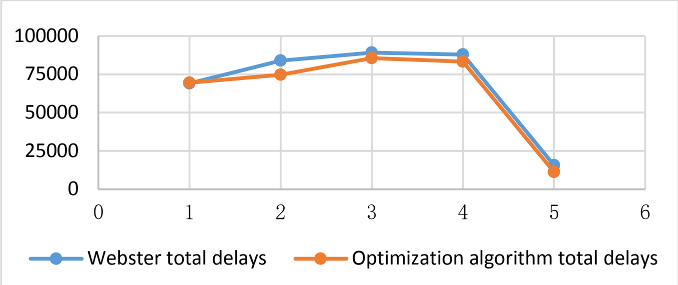

FIGURE II. COMPARISON OF DELAYED CALCULATION

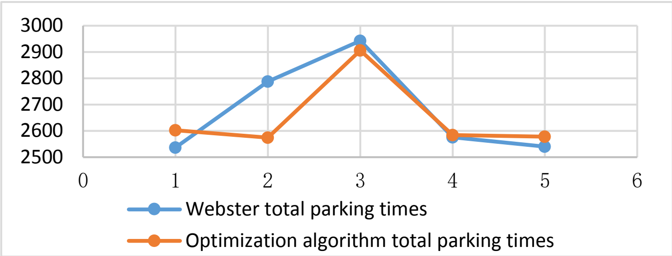

FIGURE III. COMPARISON OF PARKING TIMES

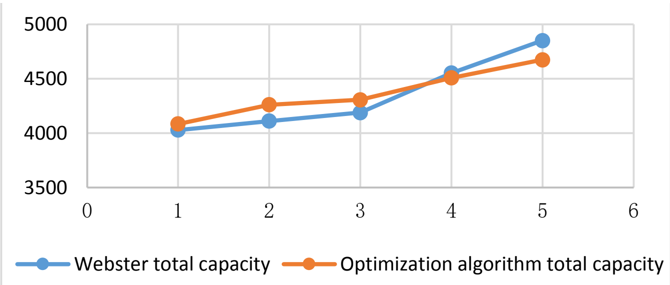

FIGURE IV. COMPARISON OF CAPACITY

From the above data, it can be seen that the optimization algorithm can significantly reduce the delay and the number of stops when the vehicles pass through the intersection, compared with the traditional Webster timing method, and the level of capacity has little advantage compared with the fixed period scheme. This may be due to the fact that the value of the capacity is relatively small compared to the value of the delay, making it difficult to take a decisive role in the calculation. This issue remains to be further improved in the follow-up work.

V. CONCLUSION AND OUTLOOK

In this paper, the signal timing of single intersection is studied. Considering the different traffic ratio, three common evaluation indexes are taken into account, such as the total delay, the total number of stops and the maximum capacity, and the objective function is established by using weighted method which solves the problem of the selection of indexes and weights under different traffic conditions. Compared with the Webster through examples, the results show that the proposed method is better than the Webster method by calling MATLAB toolbox.

ACKNOWLEDGMENT

This paper is supported by the Research Projects of the Social Science and Humanity on Young Fund of the Ministry of Education under grant No. 15YJCZH108, the Research Projects of Natural Science Foundation of Guangdong Province under grant No. 2015A030310341, and Shenzhen Science and Technology Project under grant No. JCYJ20140418091413528.

REFERENCES

[1] Li Xiaona. Study on Adaptive Control Method for a Single Intersection [D]. Dalian: Dalian University of Technology, 2006

[2] Yan Li, Lijie Yu, Siran Tao and Kuanmin Chen, "Multi-Objective Optimization of Traffic Signal Timing for Oversaturated Intersection", Mathematical Problems in Engineering[J] Volume 2013

[3] Liu Jinming. Signal Timing of Urban Road Intersections Based on Multi - Objective Programming [D]. Beijing: Beijing Jiaotong University, 2011

[4] ZHAO Wen-xiu, CAO Yong, JIN Shuo and MA Lin, "Research in Single Intersection Signal Timing Based on Two-layer Fuzzy Control" Journal of Liaoning Institute of Technology (Natural Science Edition)[J] ,vol.35,no.3,pp.148-152, Jun. 2015.

[5] Araghi.S(Araghi,Sahar), Khosravi.A(Khosravi,Abbas) and Creighton(Creighton, Douglas), "A review on computational intelligence methods for controlling traffic signal timing" , EXPERT SYSTEMS WITH APPLICATIONS[J] pp.1535-1550, FEB 15 2015.

[6] Xiaoke Zhou, Fei Zhu, Quan Liu, Yuchen Fu, and Wei Huang "A Sarsa(λ)-Based Control Model for Real-Time Traffic Light Coordination", The Scientific World Journal [J] Volume 2014