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RESEARCH ON OPTIMAL TIMING OF INTERSECTION SIGNALS BASED ON GENETIC ALGORITHM

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ABSTRACT

This paper takes the intersection of Guangzhou South Road and Yangzhou East Road as the research object, obtains vehicle delay data according to the traditional intersection vehicle delay function Webster function, and generates actual vehicle delay data according to point samples; generates vehicle delay data and point samples obtained from Webster function Carrying out data fitting on the vehicle delay data, constructing an improved intersection vehicle delay function, using this as the first objective optimization function, using an improved genetic algorithm including penalty factors to obtain the optimal signal timing plan.

KEYWORDS: Webster function; point sample method; genetic algorithm.

1. INTRODUCTION

This paper takes the intersection of Guangzhou South Road and Yangzhou East Road as the research object, obtains the theoretical vehicle delay data based on the traditional Webster function, and then uses the point sample method to collect the data of the intersection, obtains the actual vehicle delay data, and integrates the two sets of data to construct a high-precision vehicle delay function. Firstly, the field structure of the intersection such as the number of lanes was investigated to get the number of the intersection entrance lanes and the signal light timing scheme of the crossing response. Secondly, the optimization scheme of the signal timing corresponding to the actual traffic flow was calculated for simulation comparison, and the VISSIM simulation software was used for simulation. Then, the signal cycle is calculated by using the signal timing method proposed in this paper and the cycle calculated by using Webster function is compared to optimize the signal scheme and verify the effectiveness of the method proposed in this paper.

2. CONSTRUCT A HIGH-PRECISION VEHICLE DELAY FUNCTION

The intersection of Guangzhou South Road and Yangzhou East Road uses fixed timing, and the data accuracy is low. This paper obtains theoretical vehicle delay data based on the traditional Webster function, and uses the point sample method to collect data at intersections. In this way, the actual vehicle delay data is obtained. Integrate the two sets of data obtained in order to construct a high-precision vehicle delay function.

2.1 Intersection data are collected by point sample method

The point sample method is to obtain the queuing time on the entrance road through manual on-site observation for a long time at the intersection, and record the number of stops on the approach road at the entrance of the intersection in the continuous time interval on the data book. For the time interval, 15s is selected. The investigation steps are as follows:

(1) Observations were made in the morning and evening peak hours and in the peak hours, and theobservation time was controlled for half an hour each time until the required sample size was obtained.

(2) The shooting equipment is set up around the intersection to record the traffic flow at the entireintersection and obtain the required data from the video.

2.2 The traditional Webster model

This method is based on the estimation of vehicle delay at intersections by Webster model, and a series of corresponding timing parameters are determined by optimizing the cycle length. Webster method, which

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includes related principles, steps and algorithms, is a classical method of intersection signal timing calculation.

Green time ratio calculation:

$$\lambda = \frac{g_e}{C}$$

Among them： g_e is Effective green time（S）；C is signal cycle（S)。

Effective green time refers to the effective time of green signal within a signal cycle, which is the sum of phase green time and yellow light time minus the starting loss time and tail-clearing loss time。 The formula is as follows：

$$g_e = G + Y - (I_1 + I_2)$$

Starting loss time is defined as the time taken for the first car's front to reach the stop line from the start of the green light, which is called "starting loss time of the first car" and denoted as t_0；The time between the first car to the stop line and the second car to the stop line is called "first headway" and denote as h_1， h_i（$=1,2...,n$）

The calculation formula is：

$$I_1 = t_0 + \sum_{i=1}^{n}(h_i - nh_s)$$

The starting loss time was calculated by the formula, and the data was collected at the intersection. The small cars on the straight lane were investigated in the morning and evening rush hours, and the time of vehicles passing the stop line was recorded when the green light started。 The collected data were statistically analyzed and the expected values of the two sets of data were calculated. Some results were shown in Figure 1.

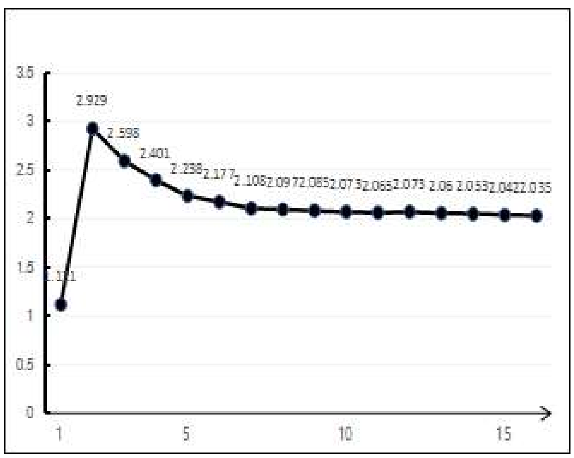

Fig. 1. Starting loss time of first vehicle and part of headway

According to the statistics, when the seventh car crosses the stop line, the fleet will reach saturation。 Therefore, the vehicle loss time consists of the headway of the first six vehicles and the starting loss time of the first vehicle。

Saturated headway $h_s = \sum_{i=6}^{16} h \approx 1.891s$ Substitute it into the formula to calculate the starting loss time I_1=3.623s .

Secondly, the tail-clearing loss time was calculated. Through the information collection on site, 500 sets of data were obtained and 489 sets of effective data were finally determined. The data distribution diagram is shown in Figure 2.

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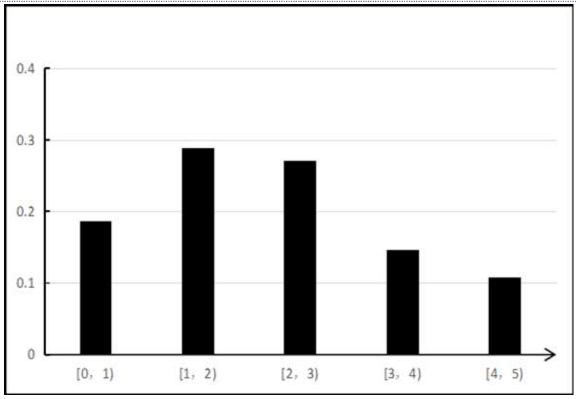

Fig. 2. Tail-clearing loss time data distribution

According to the chart, it can be determined that the frequency of tail-clearing loss time falls between [1,2) and [2,3] is high, and the expected value of the obtained data is taken $I_2 = 2.173\text{s}$. Calculate the loss time based on the data $I_1 + I_2 = 5.769\text{s}$. Once accurate data of the lost time have been obtained, the green signal ratio of each phase can be calculated：

$$\lambda_1 = 0.295005;\ \lambda_2 = 0.155829;$$
$$\lambda_3 = 0.243458;\ \lambda_4 = 0.186757$$

After obtaining the data required to calculate the delay, the vehicle delay in all directions is then calculated, and the delay calculation for each phase is constructed through parameters. The function is shown in Formula (1)：

$$d_n = \frac{C(1-\lambda_n)^2}{2(1-x_n \cdot \lambda_n)} + \frac{x_n^{\ 2}}{2q(1-x)} - 0.65\left(\frac{C}{q^2}\right)^{\frac{1}{3}} x_n^{\ (2+5\lambda_n)}$$

After the traditional Webster delay calculation results are obtained, it is necessary to carry out data fitting with the actual data collected by the point sample method, so as to reduce the error of the function by bringing the calculated data close to the actual data.

2.3 Build a function

After to get the actual delay of intersection, mining traditional Webster delay function results to actual delay data fitting method to get a new Webster has a high precision of the average vehicle delay function is used as the specified intersection delay function, the function after the fitting as shown in formula, function contains some constraint conditions.

$$f_{old}(C,\lambda_1,\lambda_2,\lambda_3,\lambda_4) = \sum_{n=1}^{4}\left\{\left[\frac{C(1-\lambda_n)^2}{2(1-x_n \cdot \lambda_n)} + \frac{x_n^{\ 2}}{2q_n(1-x_n)} - 0.65\left(\frac{C}{q_n^{\ 2}}\right)^{\frac{1}{3}} x_n^{(2+5\lambda_n)}\right] * q_n\right\}$$

$$\min f_{new}(C,\lambda_1,\lambda_2,\lambda_3,\lambda_4) = F(f_{old}(C,\ \lambda_1,\ \lambda_2,\ \lambda_3,\ \lambda_4)\ )$$

$$s.t.\begin{cases} C=\sum_{n=1}^{4} C\bullet\lambda_n+4\bullet t_y+4\bullet t_h \\ C\bullet\lambda_n\in Z^+,1\le n\le 4 \\ 15\le C\bullet\lambda_n\le 60,1\le n\le 4 \\ C\in Z^+ \\ t_y=2 \\ t_h=3 \end{cases}$$

3 OPTIMIZE SIGNAL TIMING SCHEME

Firstly, the established high accuracy vehicle delay function is taken as the objective optimization function, and the parameters of this function include the green signal ratio of each phase at the intersection λ_1, λ_2, λ_3, λ_4 And semaphore cyclesC, Total delays at intersections。 The green signal ratio and signal cycle are taken as independent variables, the total vehicle delay at the intersection is taken as independent variable, and the constant variable in the function is set as the vehicle flow at each entrance.

3.1 Genetic algorithm initializes the population

Each algorithm starts with the initialization of the population, where a random number generator is used.The population needs to be coded, and the solution space of the problem to be solved is converted through coding, and the data is converted into the form of coding.In order to ensure the accuracy of computable data, it is necessary to provide sufficient number of initial populations, so setting 60 initial populations requires 80 iterations. For each population, different signal cycles and green signal ratios need to be set, and the number format is decimal floating point system.

3.2 Genetic algorithm crossover, mutation operation

To evaluate the population of each one, during this step you need to use the suitable degree function, agreed to rely on individual fitness value in each population, to determine the replication probability of each individual, so that they can take the next step of operation, through individual selection within the parent population, need to use suitable degree function to evaluate individual, fitness is always non-negative, The crossover and mutation operations can only be carried out by selecting the individuals that meet the criteria. The crossover operation methods used in genetic algorithm are divided into single point crossover, two point crossover and uniform crossover.

（1） Single-point crossover occurs by selecting the same position on two chromosomes and swapping chromosome segments before or after the crossover breakpoint, so that two new chromosomes are obtained.

（2） Two point crossover is used to select different positions of two chromosome segments, and crossover operation is carried out after random selection.

（3） Homogeneous crossover refers to the first two crossover methods, which take all points on the whole chromosome as potential points for crossover operation, and randomly generate and perform crossover operation.

Mutation is the simulation of genetic mutations in nature. Usually, mutations are unpredictable changes caused by various unexpected phenomena. We introduce the mutation operation into the genetic algorithm to change a value in the population chromosome with a set probability, so that we can seek the optimal solution within a certain range and accelerate the convergence so as to get the optimal solution we want.

3.3 Determine the end of genetic algorithm

In reality, the signal cycle is limited, for example, the green time should not be too large or too small, so we standardize the range within [15,60], the green time taken from this range is the most realistic, the sum of the green signal ratio must be 1, etc. During the process of operation, can produce some because of the existence of the mutation operation does not conform to the qualification of the population, according to this kind of population, we will have this kind of population fitness is set to a negative number, and call the negative punishment factor, because of the high genetic algorithm always choose to fitness of the population to survive, to the rest of the population is slowly being phased out, However, the population with negative numbers can never survive, so the genetic algorithm based on penalty factor can always better obtain the global optimal solution of the objective optimization function.

Determine whether the maximum or the set number of iterations is reached. If not, the above steps need to be repeated for calculation. If it is finished, we will get the optimal solution within the limited number of calculations.

After 80 iterations, the data no longer converges, and then the optimal signal period is obtained.

4 EVALUATE AND DISCUSS MODELS

According to the known information, the entire intersection was presented on the VISSIM simulation map. In the process of drawing, the width of each entrance and approach road was determined to be 3.5 meters because of the ambiguous marking of the road on site. Meanwhile, the division of pedestrian path and non-motor lane on site was not clear, so the simulation was not carried out. In this paper, the research on the intersection is limited to the delay of motor vehicles under the new signal cycle, so other influencing factors are not considered.

After drawing the road, signal light, waiting area, driving path and traffic flow in turn in the software, we put the entire intersection into operation and set nodes at each exit to collect information on vehicle delays, complete simulation of the intersection of Guangzhou Road and Yangzhou Road, and obtain delay data through nodes. As shown in Table 1:

Table 1 Simulation results

	The delay（s)
Before optimization	81.94038
After optimization	80.19644

It can be seen from the above table that the vehicle delay of the signal timing scheme optimized by the construction of high-precision vehicle delay function and the use of genetic algorithm is significantly improved compared with the previous scheme, and the optimized signal timing scheme can better improve the traffic efficiency at the intersection. And through the simulation of the intersection, it can be known that the intersection still has the following traffic problems:

(1) Because the south entrance of the non-motor lane is too narrow, non-motor vehicle occupancy of motor lane caused by the actual vehicle delay is too large；

(2) In the channelization process, the distance between the right-turn special lane and the straight-through lane at the east entrance is too small, resulting in the conflict between right-turn and straight-through vehicles easily, resulting in a larger actual vehicle delay ratio；

(3) There is no clear phase for non-motor vehicles at the entire intersection, so it is more troublesome for non-motor vehicles to turn left.

After analyzing the domestic and foreign studies on the following model, it is found that the full speed difference model (FVD) is more practical in describing the traffic flow phenomena such as stop-go and local blocking at urban signalized intersections, and more in line with the actual traffic flow operation conditions from the physical perspective.

5 CONCLUSION

Through the use of genetic algorithm to optimize the traditional Webster model, the following conclusions are drawn:

1. The traditional Webster function is improved and the high precision delay function is obtained by fitting with the data obtained by the point sample method.
2. On the basis of the traditional genetic algorithm, the negative factor is added to make the optimal solution of the genetic algorithm more accurate.
3. The high precision vehicle delay function is constructed, and the signal timing scheme obtained by optimizing the function with genetic algorithm is verified by simulation analysis, which plays a significant role in reducing the vehicle delay at the intersection.

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