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Method and simulation of arterial coordination control based on the intensity of vehicle arrival time in connected-vehicle network[1]

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Abstract. The coordinated control of urban trunk roads played an important role in improving the capacity of urban network. In this paper, the optimization model of vehicle saturation under the condition of signal coordination control was put forward. Through the Vissim simulation analysis of the intersection of one road, the optimal allocation of signal coordination scheme was carried out. The results showed that the main traffic capacity had been significantly improved after optimization with obvious optimization effect, which had a very important reference for the improvement of urban traffic in our country.

Key words. Connected-vehicle network, arrival time, trunk coordination, Vissim simulation.

1. Introduction

With the development of economy, people are pursuing higher quality of life, and they are increasingly dependent on the freedom of the family car. The traffic jam and environmental pollution caused by this have a serious impact on the development of the city (Nellore et al., 2016) [1]. In recent years, China has carried out a wide range of infrastructure construction, but more and more traffic load makes the existing transportation infrastructure difficult to meet people's needs. The traffic congestion has become an important problem in the development of modern cities (Du T. et al., 2015) [2]. Traffic congestion makes cars in a low speed state for a long time, which can increase the amount of vehicle emissions and further deterioration of the urban environment, resulting in heavier urban air pollution. In addition, the traffic

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congestion can cause the driver's mood become irritable, which seriously affects people's life and work. It is not conducive to social stability, and it also increases the probability of traffic accident to a certain extent (Jamshidnejad A. et al., 2016) [3]. Measures should be taken to reduce traffic congestion. On the one hand is to reduce the number of vehicles. On the other hand is to strengthen the construction of road traffic facilities, and improve urban traffic capacity. One of the most important factors that cause the congestion is the bottleneck of intersections.

At present, the traffic flow control of intersection is controlled by different color lights. At the same time, the traffic control system based on the connected-vehicle network greatly improves the coordinated control of urban traffic. All directions of the road vehicle signal can be collected and sent to the traffic control system (Haddad J. et al., 2016) [4]. Through the effective control of the traffic flow, it is possible to realize the smooth traffic around the network. Vissim simulation software can be used to simulate the network analysis, and objectively reflect the relevant parameters of the network data. In this paper, the Vissim software is used to optimize the coordination control of the vehicle at the intersection of the main road, and the travel time and delay value of the vehicle are taken as the evaluation indexes. According to the optimized scheme of coordinated control, the new signal scheme is simulated and analyzed. This has played a positive role in relieving the traffic pressure and solving the problem of traffic congestion.

2. State of the art

2.1. Current situation of urban traffic control

With the continuous development of human society, urban traffic load is also growing. Although our country has made great efforts to the construction of infrastructure, the increase in population and the increase in the number of vehicles have made the city traffic very congested. Traffic congestion not only seriously affects the normal operation of the city, but also causes serious inconvenience to people's daily travel (Chow A. F. et al., 2016) [5]. In order to solve the increasingly serious traffic congestion, people use scientific traffic control system to improve the existing urban road operation. In particular, the development of traffic signals has become one of the important signs of modern urbanization. The cost is less, and the traffic efficiency can also be improved rapidly. As early as more than 100 years ago, people began to carry out the study of traffic signals, but the first was just a simple way to control the entry and exit order of intersect vehicles (Kutadinata R. et al., 2016) [6]. With the continuous development of computer technology, people have made a breakthrough in the research of technology and mechanism of urban traffic signal control (Wan K. et al., 2016) [7]. In 1920s, the control of urban traffic flow had begun to be carried out through traffic lights, which were made out with lots of simulation and modeling to develop many traffic signal control systems, such as OPAC, SCATS, SCOOT, and SPOT.

In all kinds of traffic signal control systems, SCOOT is an optimization technique of green signal ratio- cycle-phase difference, which was a new adaptive control system developed on the basis of the original TRANSYT system by the British Transport Research Institute in 1975 (Zhao S. et al., 2016) [8]. After a large number of field experiments, the system has a good application effect. In the following 20 years of development, there have been nearly 200 cities using the system. However, because the system is a centralized control model, it has some limitations in application. SCATS system is an adaptive control system developed by Australia in the 1970s, including three parts: graphical interface workstation, area control center and central monitoring system. It has the characteristics of large number, and flexible control, which has a wide range of applications in many cities of our country at present (Tao D. et al., 2014) [9]. The RHODES system was developed and implemented in the United States. It had a very significant effect at the beginning of the application, especially the effect of the traffic network was the most obvious (Kesten S. et al., 2016) [10].

The study of urban traffic control system in our country was relatively late. Until the 1970s, China began to develop and apply the traffic signal control of urban traffic trunk. After more than ten years of development, China had developed Microcomputer based arterial coordination control system based on computer. At present, China has developed dozens of traffic controllers (Sadraddini S. et al., 2016) [11]. NUTCS, China's first self-developed city traffic signal control system, is suitable for the actual traffic situation in our country, especially suitable for the traffic conditions that the density of road network is not high and the intersection space is very wide (Oskarbski J. et al., 2016) [12]. The system has the characteristics of on-line control, timing control and adaptive optimization, and the optimization of system is realized by taking into account the combination of parking times, traffic delays and congestion. However, the system also has a lot of problems. One is not fully considering the optimization of the target. The other is no comprehensive consideration of motor vehicle and non-motor vehicle control mode (Bie Y. et al., 2016) [13].

A typical traffic light control system is depicted in Fig. 1.

With the development of Internet technology, more and more applications of advanced GPS technology, sensor technology and wireless communication technology based on vehicle networking technology in the modern traffic control, vehicle networking technology can use road traffic information collection and utilization in the information platform, and realizes the coordinated management between people, road, vehicle and environment. Compared with the traditional traffic control system, the technology of vehicle networking pays more attention to the collection and processing of information, so it needs a high traffic information collection technology. The vehicle can be connected to the vehicle license plate number, owner information and other individual information, thereby accurately identify the identity of the vehicle. Once to construct a complete car networking, it can be a vehicle information acquisition is traveling on the road to the city collection network, so as to carry out data mining and analysis, control and optimization of traffic signal for the whole city, traffic control in the process of city operation, has a very important effect on the whole city traffic operation, improve the efficiency of city traffic, alleviate the traffic pressure in the city. Especially in the case of traffic accidents, can quickly understand the situation, timely traffic grooming, to avoid traffic jams. The

Fig. 1. Traffic light control system

application of RFID technology in the vehicle networking technology is also better to achieve the intelligent traffic management control, greatly enhance the level of traffic management. The application of vehicle networking technology in traffic control in our country is still in the initial stage, and there are still a lot of immature situations.

2.2. Basic theory of traffic flow

Traffic flow theory refers to the method system and model of traffic variation under the condition of certain time and space. Since it includes the relationship between human, road, vehicle and environment, the process of forming traffic flow is very complex (Xian C. et al., 2016) [14]. The parameters of traffic flow are traffic density, traffic flow and interval average velocity. Traffic refers to the number of traffic entities passing through a lane in a given period of time, which is a random variable that will vary with time and place. The average velocity of an interval is the average speed of all vehicles traveling at a given time and length. Assume that there are n vehicles with the driving road length of L. The speed of the ith car is v_i, and the average speed of the interval is v. Then we can get:

$$v = \frac{1}{\frac{1}{n}\sum_1^n \frac{1}{v_i}} = \frac{nL}{\sum_l^n t_i} \,. \tag{1}$$

Traffic density refers to the number of vehicles passing through the road at the specified time, which can reflect the degree of closeness between vehicles on the road. According to the relationship between velocity and density, the relation model of velocity-density can be obtained:

$$v = v_{\mathrm{f}} - \frac{v_{\mathrm{f}}}{\rho_{\mathrm{j}}}\rho = v_{\mathrm{f}}\left(1 - \frac{\rho}{\rho_{\mathrm{j}}}\right) . \tag{2}$$

If the speed is close to 0, we can use the 1961 Underwood index model:

$$v = v_{\mathrm{m}} \ln\left(\frac{\rho_{\mathrm{j}}}{\rho}\right) . \tag{3}$$

When traffic is small, cars can run in both directions unblockedly, and the logarithmic model proposed by Green Bai can be used:

$$v = v_{\mathrm{m}} \mathrm{e}^{-\frac{\rho}{\rho_{\mathrm{m}}}} . \tag{4}$$

Here, the traffic free flow speed is v_{f}, the flow rate reaches the maximum when the speed is the critical speed v_{m}. Symbol ρ stands for the traffic density, the maximum flow of the optimal traffic density is ρ_{m}.

For the analysis of traffic flow, no matter what kind of mathematical statistical method is used, it will be random to some extent. Generally, there are two kinds of methods for statistical distribution: (1) using the continuous distribution as a tool to study the statistical characteristics of the time interval of the events occurring in the traffic flow; (2) using discrete distribution as a tool, it is necessary to achieve a certain period of time. In the calculation of the number of vehicles arriving in the interval, the discrete distribution can be used, which includes binomial distribution, negative binomial distribution and Poisson distribution (Yan F. et al., 2016) [15]. When using a continuous distribution to describe the distance between vehicles to reach, we need to select a specific distribution according to different occasions and the velocity distribution, and the commonly used distributions are the displaced negative exponential distribution, exponential distribution and so on.

3. Methodology

3.1. Signal coordination control

The quality of the main road traffic has a direct impact on the surrounding road traffic. This is mainly due to the large traffic flow on the main line, and it is also the traffic flow collecting and distributing center of multiple signal intersections. Under the influence of mixed traffic and other external interference factors, the simple traffic signal control is difficult to separate the traffic flow of human and non-motorized vehicles. In order to obtain more smooth communication and ensure traffic safety, it is necessary to reduce the speed of the vehicle through the intersection of each trunk. In the main road traffic flow control, we need to pay attention to the following points:

(1)–The traffic flow can show good continuity and reach the intersection as evenly as possible.

(2)–The peak and non-peak hours of urban traffic every day make the traffic flow change with time and show heterogeneity. Coordinate and control according to the characteristics of traffic flow in different periods.

(3)–Ensure the distance between the adjacent intersections. Only if the distance is long enough, the vehicle at the front intersection will reach the front intersection at random.

(4)–Give priority to the coordinated control of traffic flow on the main road of one-way traffic.

(5)–According to the type of the intersection of the main road, the system is chosen to control the system by the use of as little as possible phase.

In the process of arterial road coordinated control, it is necessary to understand the current situation of traffic flow, and then optimize the signal timing according to the relevant data. In the system, the longest intersection is the critical intersection. When the signal coordination is optimized, the key intersection is considered. The design flow of traffic signal coordination control is shown in Fig. 2.

Figure 3 is the time distance map that reflects the motion of the vehicle. The horizontal and vertical coordinates in the figure represent distance and time, respectively. Using the data of each intersection, we can draw a specific time distance map. The diagonal line in the graph represents the driving process line of the first vehicle in each cycle. Assuming a constant speed, according to the specific traffic flow at the intersection, the traffic lights are set. Assume that all vehicles through the intersection can avoid the red light stop.

The key of the scheme design is to determine and optimize the phase difference in the design of arterial system timing scheme. The most commonly used method is the maximum green wave method, and the specific way of thinking includes graphic method and numerical method. The graphic method is to use the color of the signal in the time-distance graph as the time function, so as to draw the coordination control chart of the signal lights. The synchronous or interactive coordinated control system is established in order to realize the repeated adjustment of broadband, and get the phase difference and the ideal green wave band. The optimal control of

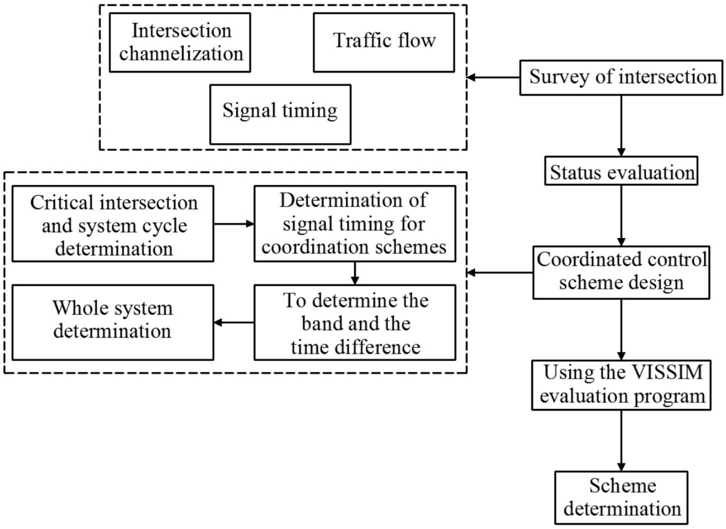

Fig. 2. Signal coordination control system design flow

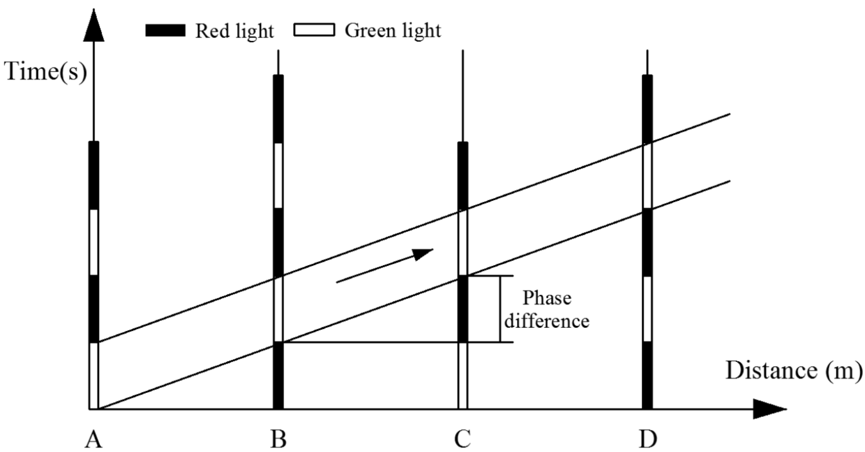

Fig. 3. Time distance graph of four adjacent intersections

the system by numerical solution is to find out the maximum diversion distance between the actual signal and the ideal selected signal of intersections, so as to find the optimal phase difference control scheme.

3.2. Coordinated optimization control of arterial signal

When the signal coordination optimization is carried out, the minimum delay method can be used to realize the minimized vehicles delay, so as to provide green band with enough wide for arterial vehicles. The main goal of arterial optimization is to minimize the total delay. The mathematical model is built by the relationship between the delay and the phase difference. The optimal phase difference is determined by optimization. From the vehicle intensity, we should choose different formulas according to different saturations. When the saturation is more than 0.9, we can choose the Akcelik transient delay model. When it is less than 0.9, the Webster steady-state model can be chosen. Assume that the average delay time of each vehicle in the vehicle group is d, the cycle time is c, the green ratio is λ, and the saturation is x. When the saturation is less than 0.9, the formula of the Webster model is

$$d = \frac{c\,(1-\lambda)^2}{2\,(1-\lambda x)} + \frac{x^2}{2q\,(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{\frac{1}{3}} x^{(2+5\lambda)}\,, \tag{5}$$

$$X_i = \frac{q_i}{CAP_i}\,. \tag{6}$$

When the saturation is greater than 0.9, the calculation formula of the Akcelik transient delay model is:

$$d = \left\{\begin{array}{l} \frac{c\left(1-\frac{g}{c}\right)^2}{2\left(1-\left(\frac{g}{c}\right)x\right)} \cdots\cdots x < 1 \\ \frac{c-g}{2} \cdots\cdots x \geq 1 \end{array}\right\} + \frac{Q_0}{c}, \tag{7}$$

$$x_0 = 0.67 + \frac{s_g}{600}\,. \tag{8}$$

Here, the saturation flow rate of the lane is x_0, and the average queue length is Q_0 in the observation period. The traffic delay for the entrance road is d_{ij}, and the traffic volume in the road entrance is q_{ij}.

On this basis, the model is optimized, that is, the objective function is located at the intersection of the total delay value. Then we can get

$$D = \sum_i \sum_j d_{ij} q_{ij}\,. \tag{9}$$

The minimum delay is taken as the objective function and the constraint condition of the signal cycle length when calculating it with the saturation value is as follows

$$20n \leq C \leq 60n\,. \tag{10}$$

In order to realize that the cycle time of the intersection of the main road is the sum of the effective green time and the loss time of each phase, the following formula should be met

$$\sum_{i=1}^{n} g_i + L = C\,. \tag{11}$$

The objective function of the minimum delay is

$$\text{s.t.} \left\{\begin{array}{l} 20n \leq C \leq 60n, \\ \sum_{i=1}^{n} gi + L = C. \end{array}\right. \tag{12}$$

After the model is determined, it is necessary to calculate the traffic capacity and the saturation of the intersection according to the actual situation of the intersection. The initial value of the delay is calculated according to the selected model, and the effective green time of the intersection is adjusted in accordance with the square reverse, so as to get the best effective green time and cycle time.

4. Result analysis and discussion

Arterial signal coordination control method based on optimization is used to carry out Vissim simulation and analysis of a traffic road intersection. A detector is arranged in each direction of each intersection to detect the traffic flow in different directions, and the obtained monitoring data is directly applied to the signal lamp in the direction. The main road is two-way with four lanes, a total of 1 km. The intersections of the study area are numbered 1, 2, 3, and 4, respectively. The optimization is carried out through the signal coordination scheme. The phase diagram of the intersection of the main road is shown in Fig. 4. In addition to the right turn phase in the No. 4 intersection, the right turn of other intersections is not controlled by the signal.

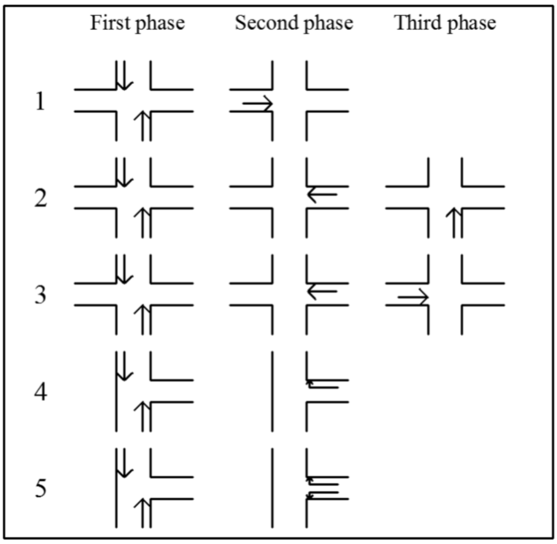

Fig. 4. Arterial intersection phase diagram

Based on the existing optimization scheme, the Vissim software is used to optimize the control scheme. Using this software, it can directly reflect the real-time situation of intersections, vehicles and roads in the road network, and record the change process of the related elements. After drawing a map, the plane graph of the intersection is set to be the simulation map. Then the road network is established, and the traffic structure is defined according to the network situation. A detector is set in the road network according to the path. The delay, travel time and queue length are obtained by simulation. According to the simulation, we get the average value of the delay of the vehicles at the intersection of the main road, as shown in Table 1. It can be seen that the delay value of the east road of No. 2 intersection, the west and north road of No. 3 intersection is relatively large.

According to the simulation results of the current situation, the key traffic direction signal phase and traffic flow ratio of each intersection are determined, and the optimal signal period is calculated. After the optimization of the arterial road coordinated control simulation analysis, the simulation results are shown in Table 2.

Table 1. Road intersection signal timing (t/s)

Intersection number	1	2	3	4	5
Period (s)	85	120	130	100	95
Phase 1	55	50	55	70	60
Phase 2	20	25	35	20	25
Phase 3	-	30	25	-	-

Table 2. Comparison of delays of each entrance in the intersection

Intersection number	Present situation				After optimization			
	East	West	South	North	East	West	South	North
1	-	72	15	15	-	69	4	10
2	194	-	22	37	167	-	4	15
3	6	203	53	117	2	198	46	72
4	26	-	14	24	24	-	9	19
5	29	-	21	20	12	-	14	12

Through the simulation results, we can see that the travel time and delay of each intersection in the route are reduced compared with that before the optimization. The travel time of the intersection is reduced by 13 %, 23 %, 16 %, 21 %, and 46 %, respectively, and the delay value is reduced by 19 %, 26 %, 16 %, 19 % and 46 %, respectively. Thus, the optimization effect is obvious. The indicators based on the travel time and the average delay of vehicles can significantly improve the traffic conditions, and road traffic capacity has been greatly improved.

5. Conclusion

The problem of urban traffic congestion has become one of the most important factors that restrict the development of cities. The optimal control of traffic flow could effectively improve the urban traffic congestion. According to the saturation of different models, different models were chosen for the optimal control of the main road signal. When the saturation was more than 0.9, we could choose the Akcelik transient delay model. When Webster was less than 0.9, the steady-state model could be chosen. In this paper, Vissim simulation software was used for the optimization control analysis of the intersection of a main road based on the traffic network. Through the analysis of the data of four intersections, the comparative analysis of the travel time and delay before and after optimization was carried out. It could be seen that after the optimization of each intersection, the travel time of the intersection was reduced by 13 %, 23 %, 16 %, 21 %, and 46 %, respectively, and the delay value was reduced by 19 %, 26 %, 16 %, 19 % and 46 %, respectively. Therefore, the traffic capacity of the intersection of the main road had been significantly improved by optimizing control. In the following research, the optimal control scheme can be applied to the intelligent traffic control system.

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