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A Coordinated Control Algorithm for Pedestrian Crossing in Road Sections Considering Safety and Efficiency

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ABSTRACT: In order to further improve the efficiency and safety of pedestrians crossing the street and vehicles between two adjacent intersections, taking some sections of Liuquan Road in Zibo Hi tech Zone as an example, an optimal coordinated control method of pedestrian crossing signals and intersection signal lights is designed through Webster model. The experimental results are simulated and analyzed with Vissim software. The results show that: (1) The average delay time of pedestrians crossing the 30m crosswalk is 10.16s through the analysis of pedestrian crossing demand and traffic flow data during peak hours; The average parking delay of motor vehicles at the crosswalk is 9.6s; (2) By calculating the saturation flow, timing parameters and signal timing at the crosswalk, trunk signal coordination is carried out on this section to realize the "green wave" traffic of the road. (3) The basic road network, as well as the basic information of flow and path, are established by using Vissim software. The signal timing before and after coordination is set, simulated, and the delay comparison of vehicles on the coordinated trunk road before and after coordination is obtained by using node evaluation.

KEYWORDS: Adjacent intersections; Section crosswalk; Traffic signal coordination control; Green wave

I. INTRODUCTION

According to the survey of the World Health and other relevant organizations, about 1.25 million people die every year in the world due to road traffic accidents, of which pedestrians, motorcyclists and cyclists account for 49%. Especially at the crosswalk of the non motor vehicle and pedestrian mixed section without signal control, the phenomenon of people and vehicles scrambling for the right of way is common, and the phenomenon of people and vehicles conflict is serious, which has aroused widespread concern of the international community.

At present, Kayvan Aghabayka et al. have investigated and analyzed two signalized and unsignalized crosswalks in Tehran, and found that men prefer to cross when the red light flashes; Older people are more cautious at signalized intersections than at unsignalized intersections; The pedestrians who receive and call mobile phones and listen to music only look at the ground when crossing the crosswalk, without observing whether there are oncoming vehicles on both sides [1]. Muley et al. found that the speed of pedestrians crossing the street is positively correlated with the length of the crosswalk [2]. Paulo Anciaes et al. analyzed the interaction data between 937 drivers and pedestrians at 20 intersections in the UK, and found that all stripes, color/texture surfaces, visual narrowness and ramps considered increased the tendency of the first car and any car to stop [3]. The influencing factors of whether pedestrians cross the street mainly depend on people's visual perception of the moving characteristics of approaching vehicles. Lower speed and longer distance will lead to longer travel time and reaction time, while hearing has no significant impact on it [4].

In order to analyze the influencing factors of pedestrian crossing speed, the pedestrian crossing behavior and status of 7 typical signal intersections in Chongqing were investigated, and it was concluded that the age, green light period, crosswalk length, secondary tasks, land use nature and demand speed of pedestrians all had an impact on their crossing speed [5]. When crossing the street, the speed of men is obviously higher than that of women. The older they are, the slower they cross the street [6]. Different age groups and different traffic behavior tendencies also have a certain

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impact on pedestrian crossing, and the safety levels are in order of stability, influence, thinking and dominance [7]. The analysis of the elderly special population crossing the street shows that at the signal intersection, when the proportion of the elderly is between 21% and 41%, the pedestrian crossing design speed is 0.94m/s-1; When the proportion of the elderly exceeds 41%, the design speed of pedestrian crossing is 0.86m/s-1 [8].

Aiming at the problem of uncoordinated pedestrian crossing signal control of adjacent crosswalks, the phase duration of motor vehicles, green light time of pedestrians and phase difference are used as parameters to establish a real-time signal control model for pedestrian crossing of adjacent crosswalks on the road section with the lowest average delay of vehicles and pedestrians, so as to maximize the comprehensive passing efficiency of vehicles and pedestrians [9]. Therefore, it is an important guarantee to improve the road service level to coordinate and control the horizontal and vertical signals of pedestrians and vehicles at the upstream and downstream intersections and pedestrian crossings. This paper will establish a signal control method for coordination between upstream and downstream signalized intersections and multiple pedestrian crossings on the road section.

Investigation And Analysis Of Current Data Road Overview

Some sections of Liuquan Road (from Zhongrun Avenue to Liantong Road) in Zibo High tech Zone are selected, with a length of 30m and a width of 9m (4m for pedestrians and 2.5m on both sides of non motor vehicles). The geometric structure of the road is shown in Figure 1 below. The signal intersection A on this section is the intersection of Zhongrun Avenue and Liuquan Road, E is the intersection of Liantong Road and Liuquan Road, and the crosswalk between the two intersections is marked as B, C, D from north to south, The pedestrian crossing at B and D has signal control, but it is not coordinated with the upstream and downstream. The pedestrian crossing at C is an intersection without signal control. The three crosswalks are located in commercial land, residential land and government land respectively, and the demand for pedestrian crossing is large.

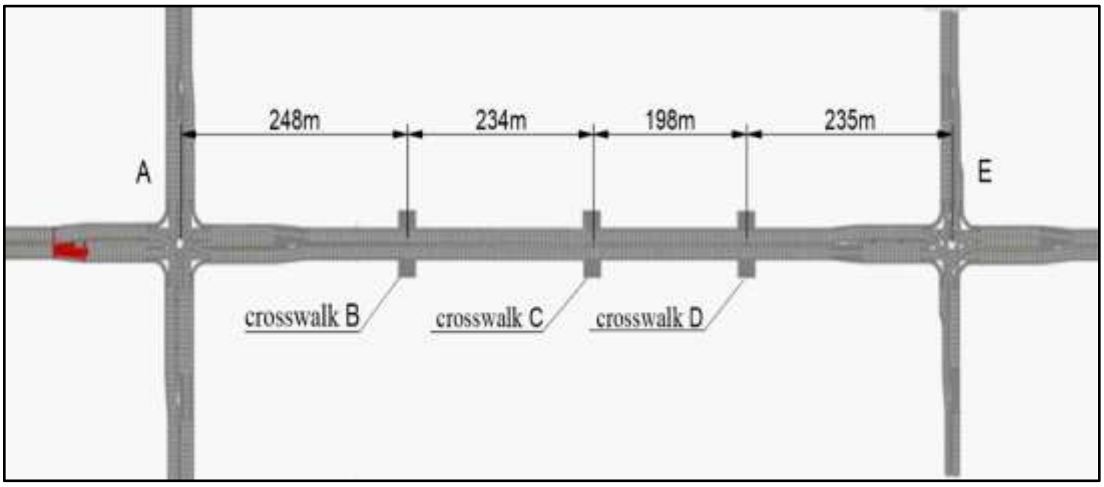

Fig.1 Crosswalk of Liuquan Road (Section from Zhongrun Avenue to Liantong Road)

TRAFFIC FLOW SURVEY

The method of video recording and on-site recording is used to investigate the traffic flow of pedestrian crossing upstream and downstream intersections in peak periods. The traffic flow statistics table is shown in Table 1.

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Table 1 Statistics of the number of motor vehicles at each entrance of intersections (pcu/h)

INTERSECTION	ENTRANCE ROAD	traffic flow		
		Turn left	go straight	turn right
LIUQUAN ROAD - ZHONGRUN AVENUE	Westbound	439	1242	293
	Eastbound	252	695	455
	Northbound	474	1332	163
	Southbound	348	1140	385

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LIUQUAN ROAD - LIANTONG ROAD	Westbound	420	786	197
	Eastbound	223	523	318
	Northbound	348	1206	186
	Southbound	216	1338	391

According to the flow statistics of the two intersections, during the late peak period, the flow of the section between Liuquan Road and Zhongrun Avenue, Liuquan Road and Liantong Road is 2034pcu/h from north to south, and 1626pcu/h from south to north. The pedestrian crossing flow at the evening peak (17:00-18:00) of this section was investigated by video recording, and the demand for pedestrians crossing the street from east to west and from west to east at B was converted into 788 persons/h and 588 persons/h respectively, most of whom were electric vehicles; The cross street flow from east to west and from west to east at point C is 1584 persons/h and 1445 persons/h respectively, and the total flow of the crosswalk in this section during the investigated late peak hours is 3029 persons/h. Among them, pedestrians and electric vehicles account for most of the street crossing traffic, and electric vehicles account for 57% of the pedestrian crossing traffic; The street crossing flow from east to west and from west to east at location D is 104 persons/h and 164 persons/h.

Critical gap refers to the maximum time interval for a single pedestrian to refuse to pass a signalized intersection. When the gap between traffic flows is not enough for pedestrians to cross, that is, when the crossing gap is less than the critical crossing gap, pedestrians crossing the street need to wait for vehicles to pass before looking for a crossing gap. At this time, the average waiting time of pedestrians is：

$$\bar{h} = \frac{\int_0^t hf(h)dh}{\int_0^t f(h)dh} = \frac{\frac{1}{\lambda} - (t + \frac{1}{\lambda})e^{-\lambda t}}{1 - e^{-\lambda t}} \quad (3)$$

The probability that pedestrians can cross after arriving is：

$$P(h > t) = e^{-\lambda t} \quad (4)$$

The distribution of pedestrian arrivals is listed as：

$$P(x = k) = (1 - e^{-\lambda t})^k \cdot e^{-\lambda t} \quad (5)$$

The number of intervals for pedestrians to wait is：

$$\bar{x} = \sum_{k=1}^{\infty} k \times P(x = k) = \frac{1 - e^{-\lambda t}}{e^{-\lambda t}} \quad (6)$$

II. SIGNAL COORDINATION CONTROL METHOD

CALCULATION OF PEDESTRIAN DELAY

At the crosswalk crossing at the non signal control section, the delay of pedestrians crossing the street is affected by the headway of vehicles on the road. This paper takes the crosswalk C at the section as an example to calculate the delay of pedestrians. The B and D sidewalks are analogically derived. The safe crossing clearance for pedestrians is：

$$t = \frac{L}{v_c} + \frac{S}{v_r} \quad (1)$$

Where, S—Width of single lane, 3.5m in this article

L—Stopping sight distance at a certain speed, 3.5m in this article

v_c—The value in this article is 20km/h

v_r—Pedestrian crossing speed, 1.2m/s

Thus, t=3.55s. This road section meets the above conditions of negative exponential distribution, and the probability density function of negative exponential distribution is：

$$f(h) = \lambda e^{-\lambda h}, h \geq 0 \quad (2)$$

Therefore, the delay time of pedestrians crossing a lane is：

$$d = \bar{x} \times \bar{h} = \frac{\frac{1}{\lambda} - (t + \frac{1}{\lambda})e^{-\lambda t}}{e^{-\lambda t}} \quad (7)$$

Where：λ——Vehicle arrival rate

K——number of vehicle intervals.

According to the recorded video, the average arrival rate of vehicles in each lane of the crosswalk from south to north is 0.195 vehicles/s, and the average arrival rate of vehicles in each lane from north to south is 0.13 vehicles/s. According to the above formula, the average delay time of pedestrians crossing the 8 lanes here is d=10.16s.

TIMING DESIGN OF INTERSECTION SIGNAL LIGHTS

According to the actual flow characteristics of the two upstream and downstream intersections in different directions, the Webster cycle model is used to determine the cycle length of the two intersections as 198s and 154s respectively. Take

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198s as the public cycle length of trunk line coordination timing, and the intersection of Liuquan Road and Zhongrun Avenue as a key intersection. According to the length of the common cycle, the timing of non critical intersections (Liuquan Road and Liantong Road intersection) is recalculated. As a critical intersection, the timing scheme of Liuquan Road and Zhongrun Avenue intersection is the same as that of a single intersection.

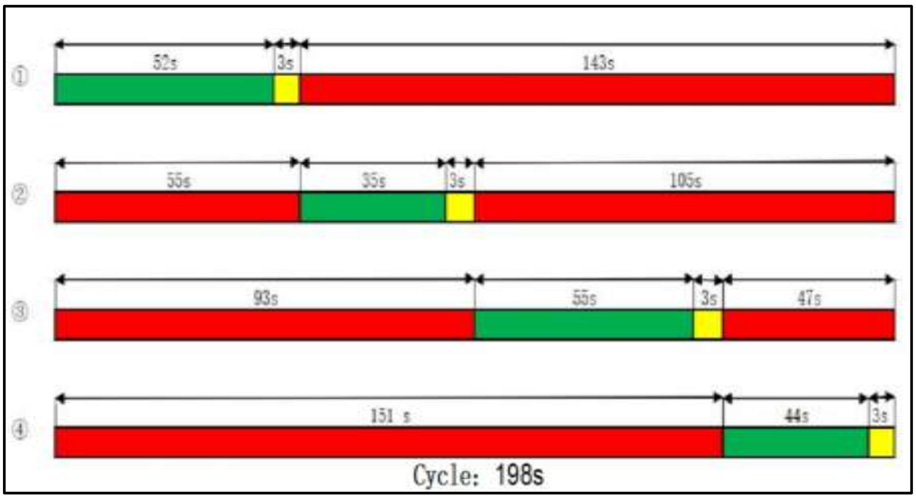

Fig.2 Signal Timing and Phase Diagram of Key Intersections

According to the above formula, the coordination phase diagram of non-key intersections (LiuquanRoadand Liantong Road intersection) is shown in the following figure：

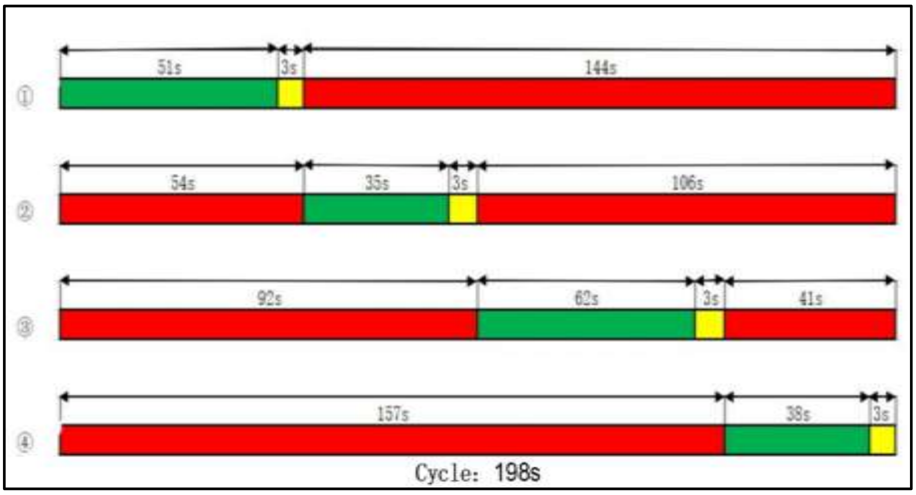

Fig.3 Signal timing and phase diagram of non-key intersections after coordination

TIMING OF PEDESTRIAN CROSSING

The setting of crosswalk signal lights must ensure the time required for pedestrians to cross the street to ensure the safety of pedestrians. The minimum green light time for pedestrians crossing the street is:

$$G_p^{\min} = 7 + \frac{D}{v_p} - I \qquad (8)$$

Where：D—length of crosswalk, m；

V_p—pedestrian speed, 1.2m/s in this article；

I —Green light flashing time, 5s in this article.

The length and width of the crosswalks at B, C and D on the section between Liuquan Road Zhongrun Avenue and Liuquan Road Liantong Road studied in this paper are 30m and 9m respectively. According to the above formula, the minimum green light time for pedestrians to cross the street is 27s. It is estimated that the pedestrian crossing time can meet the demand of pedestrians in 198s public cycle.

GREEN WAVE DESIGN

Green wave design is carried out according to the coordinated signal timing of Liuquan Road and Zhongrun Avenue, Liuquan Road and Liantong Road, and the signal timing of crosswalks. Three crosswalks are regarded as three intersections, so there are five intersections. According to the phase difference calculation of the green wave belt, the phase difference of each intersection from north to south on the selected road section is 0s, 5s, 145s, 95s and 190s in sequence. Push the green wave at a belt speed of 40km/h. It can be seen from the bandwidth of the uplink and downlink green wave bands that the bandwidth of the uplink green wave band is (45s, 57s, 36s, 36s from left to right) and the downlink green wave band is (26, 35, 35, 48 from left to right).

Through this design scheme, vehicles crossing two intersections and three sections under the control of pedestrian crossing annunciators only need to stop once, which has significantly improved the effect of stopping and passing compared with pedestrian crossing in each section before, and the traffic operation efficiency has been effectively improved, and pedestrian crossing has also been well guaranteed regularly and rhythmically.

III. VISSIM SIMULATION

The current signal timing and the signal timing after coordinated control of trunk roads are respectively imported into the vissim simulation platform to obtain the average value of parking delay, average value of vehicle delay, queue length, maximum queue length and other basic evaluation indicators. Finally, the simulation evaluation results are obtained. Table 2 and Table 3 can be obtained by analyzing the results output by the vissim simulation software.

Table 2Queue length and delay before coordinated control

Direction	Variables	At the crosswalk	Liuquan-Zhongrun intersection	Liuquan-Liantong intersection
From south to north	Queue length/m	18.85	55.39	59.46
	Maximum queue length/m	158.27	164.62	167.38
	Average value of vehicle delay/s	33.23	91.06	56.37
	Average value of parking delay/s	22.38	83.76	47.22
From north to south	Queue length/m	16.58	49.63	103.89
	Maximum queue length/m	145.93	133.7	250.76
	Average value of vehicle delay/s	26.17	56.22	90.45
	Average value of parking delay/s	16.76	47.68	81.11

Table 3Queue length and delay after coordinated control

Direction	Variables	At the crosswalk	Liuquan-Zhongrun intersection	Liuquan-Liantong intersection
From south to north	Queue length/m	6.05	43.44	43.14
	Maximum queue length/m	89.17	127.92	136.1
	Average value of vehicle delay/s	22.46	67.14	46.87
	Average value of parking delay/s	6.29	60.93	39.88
From north to south	Queue length/m	1.8	40.8	80.67
	Maximum queue length/m	58.81	133.29	277.92
	Average value of vehicle delay/s	18.49	43.85	56.02
	Average value of	3.19	37.39	49.77

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	parking delay/s			

According to Table 2 and Table 3, after the coordinated and unified control of the upstream and downstream intersections and the crosswalks of the road sections, the average delay of the traffic flow at the two intersections and the crosswalks of the road sections, as well as the queue length and the maximum queue length have been improved. Therefore, by coordinating the signal control between the upstream and downstream intersections and the crosswalk of the road section, it is beneficial to reduce the delay of traffic flow and ensure the safety of pedestrian crossing at the crosswalk of the road section.

IV. CONCLUSION

Through field investigation and data analysis, this paper uses Webster model to design an effective linkage control method for signal timing of pedestrian crossing at two adjacent intersections and crosswalks on their sections. Finally, the validity of the scheme is verified by Vissim simulation. The signal coordination control method proposed in this study, which considers the upstream and downstream signal intersections and multiple pedestrian crossings in the middle section, not only effectively solves the conflict between pedestrian crossing and motor vehicle traffic during peak hours, but also improves the traffic efficiency of pedestrian and vehicle sections, which is worthy of promotion and application under similar conditions.

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