Study on Signal Control Mode of Roundabout Based on VISSIM

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***Abstract*—The traditional roundabout adopts the way of priority control. However, with the increasing of urban vehicles, the conflicts of traffic flows frequently happened among the vehicles in the no signal rotary intersection. It is difficult for the weaving vehicles to get out of the circulating lane in time which can result in the increase of the delay, queues length, congestion and even lock-up. Aiming at the problem of signal control in roundabout, this paper takes Dalian Shuma Square as an example, and uses VISSIM software to simulate the modeling. Meanwhile, priority control, each phase for entrance control and two-step left control methods under different flow rates conditions was used in the simulation. The average queue length, average delay and the saturated degree were used as key indicators to evaluate the efficiency of roundabout with different control methods, and the applicability of the three control methods was obtained which can provide a reference for the choice of control modes of roundabout.**

***Index Terms*—roundabout; VISSIM; traffic control**

I. Introduction

The roundabout is a kind of intersection that can be self-adjusted. It sets the island at the center of the intersection, allowing the vehicle to enter the counterclockwise circle around the island and uses the loop to organize canalized traffic [1]. The design of roundabouts is simple. Compared with common crossroads, it has the advantages of continuous traffic flow, less conflict points, beautiful structure and elegance, etc. [2]. It is widely used in early cities in China. However, the uncontrolled roundabout is only suitable for sections with low flow. Once the traffic volume increases, uncontrolled roundabouts cannot self-adjust to meet traffic demand, and queue lengths and delays will greatly increase, and even lock-up.

Most domestic scholars usually adopt the following three solutions: ①Remove the roundabout and replace it with a normal signal-controlled intersection; ② Widening the entrance and exit, using left turn, right turn, straight lane; ③Using signal control. The first two modifications require more capital, a large amount of engineering, and have limitations when used. Using the signal control of uncontrolled roundabouts is not only simple, convenient, and economical, but also effective in relieving traffic pressure.

In view of this situation, based on the VISSIM, this article takes Shuma Square in Dalian as an example, and applies three control methods: priority control, each phase for entrance, and two - step left control, and gradually increase the intersection traffic. By comparing the average delay, average queue length and saturated degree of the three different control methods at the same flow rate. A comprehensive evaluation of the intersection is made to determine the merits of the three control modes under different traffic flow and the applicable scope of the three control modes.

II. Three Roundabout Control Methods

A. Priority Control

Priority control roundabouts are self-organized intersections. Vehicles that have entered roundabouts have priority. The sign at the intersection will indicate that the vehicle entering the roundabout is decelerating, and the vehicle already in the roundabout needs to be advanced, but as the traffic volume increases rapidly, priority control roundabouts are increasingly congested and it is difficult to meet the current traffic demand.

B. Each Phase for Entrance Control

Each phase for entrance control is one of the common signal control methods for a roundabout. Each entrance is used as a single phase. Left-turn vehicles and straight-through vehicles in each entrance are released at the same time. Separating conflicting traffic flows through this type of control. Because the green light duration can be set according to the flow of each entrance, it is possible to better balance the flow of traffic [3].

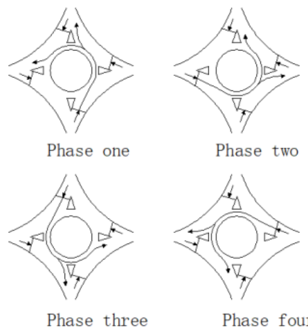

Figure 1. Each phase for entrance control phase

Manuscript received August 16, 2018; revised November 8, 2018.

doi: 10.18178/jtle.6.2.43-47

Each phase for entrance control generally adopts a four-phase sequential release mode to minimize the loss among the phases of the roundabout, and the phase is shown in Fig. 1.

C. *Two - Step Left Control*

Since the 1990s, the traffic has grown rapidly, and the regular roundabouts have begun to experience congestion and incompatibility has gradually emerged. Yang Xiaoguang, Peng Guoxiong and others have conducted theoretical and practical studies on signal control methods for roundabouts and proposed left-turn secondary control methods to solve congestion [4].

Two - step left control is adopted at the first parking line, which combines left-turn traffic flow to meet the constraints of loop capacity, and at the same time, improves the efficiency of straight-line vehicles. The second parking line is also controlled by two phases. Left-turning vehicles on the ring road use the green light interval between the two phases of the entrance road. When the north and south entrances are released, they form the same phase as the left-turn traffic on the east-west traffic on the ring road; when the east-west entrance is released, they form the same phase as the south-north left-turn traffic flow waiting on the ring road. The phase is shown in Fig. 2.

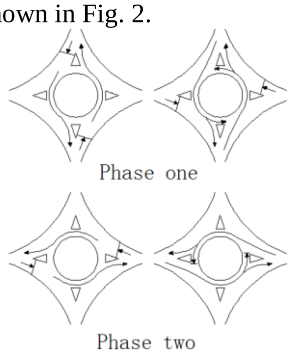

Figure 2. Left-turn secondary control phase

III. SIGNAL TIMING

A. *Each Phase for Entrance Signal Timing*

1) *Entrance lane setting*

The purpose of implementing signal control is to make the vehicles avoid collisions within the loop, and the flow of traffic in different directions is separated in time. In order to facilitate the implementation of signal control, it is necessary to divide the entrance into left-hand traffic, right-hand traffic and right-turn dedicated traffic lanes, so that each traffic flow will follow its path and avoid cross-contrast.

2) *Signal timing*

Suppose the radius of the loop is r_0, the width of each loop is w, the design speed of the roundabout is v_0, the angle between the entrance and the collision point is α, the distance from each entrance vehicle to the conflict point near the intersection is s:

$$s = \frac{\pi\alpha}{180}(r_0 + \frac{1}{2}w) \tag{1}$$

The interval of the two phase green lights is I:

$$I = \frac{s}{v_0} \tag{2}$$

B. *Two - Step Left Control Signal Timing*

1) *Parking line settings*

The two - step left control method is based on the following: First, set the first parking line, dedicated left-turn lane, and dedicated left turn signal at the entrance; then, the second parking line is set up before the left-turn traffic on each lane of the ring road collided with the left-turn traffic and the traffic flow of the opposite lane, and added a special signal light for left-turn vehicles on the roundabout [5]. Therefore, the left-turning traffic flow at each entrance will be driven out of the loop after two signal controls. Specific parking line layout shown in Fig. 3.

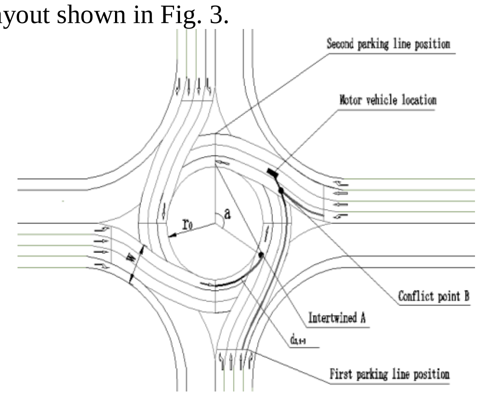

Figure 3. Ring capacity diagram

2) *Loop capacity*

Assume that the central angle is α (As shown in Fig. 3), "i" is the i-th intersection. The distance from the second parking line corresponding to the intersection $i-1$ to the interlacing point A_i is $d_{2,i-1}$. Then the queuing length of a left-turn lane is l_i

$$l_i = \frac{\pi\alpha}{180}(r_0 + \frac{1}{2}w) + d_{2,i-1} \tag{3}$$

The capacity of a left-turn lane at an intersection is

$$C_{1,i} = \frac{l_i}{5} = \frac{1}{5}[\frac{\pi\alpha}{180}(r_0 + \frac{1}{2}w) + d_{2,i-1}] \tag{4}$$

3) *Signal period*

The vehicle needs to be parked on the left-turning lane, so each cycle must be such that the left-turning waiting vehicle is emptied from the lane. Left-turn vehicle emission time is t_{ci}

$$t_{ci} = (c_{1,i} - 6) * \frac{1}{s_c} + 19.5 \tag{5}$$

s_c is the saturated flow rate on the loop, so the shortest signal cycle c_c of the loop is

$$c_c = \sum_{i=1}^{k}(t_j + l_j) \tag{6}$$

k is the number of phases in one cycle, t is the maximum time for left-turn traffic flow in each phase, and l is the phase loss time.

C. Optimal Signal Period

There are many methods of signal timing at roundabouts, such as the F-B method, HCM method, and ARRB method, all derived from the Webster model[6].

Yang Xiaoguang focused on the special control method of signal control roundabouts and used theoretical analysis combined with computer simulation methods to give an optimal cycle control signal rounding with high accuracy and reliability [7]. The cycle time of the mode is:

$$C_0 = \frac{1.05L + 2.5}{1 - Y} \tag{7}$$

So the left-turn secondary control cycle time is

$$c = \max\{c_0, c_c\} \tag{8}$$

IV. VISSIM Simulation Method

VISSIM is a microscopic traffic flow simulation system software developed by the German PTV [8].

A. Intersection Design and Traffic

Shuma Square's traffic volume is large, and the flow of people and traffic is relatively concentrated during the rush hours.

The island is 64 meters in diameter. It consists of four lanes. Left-turn traffic accounts for 21.56% of total traffic, right-turn traffic accounts for 33.09% of total traffic, and direct traffic accounts for 45.35% of total traffic. Therefore, the lanes are divided during simulation. 1 left turn lane, 1 right turn lane, 2 straight lanes.

TABLE I. Traffic Survey in Dalian Shuma Square Roundabout (pcu/h)

	Straight	**Turn left**	**Turn right**	**Total**
West bound	240	102	276	618
East bound	342	252	384	978
North bound	498	186	240	924
South bound	384	156	168	708
Total	1464	696	1068	3228
Ratio	45.35%	21.56%	33.09%	100%

Based on the original data, this paper maintains the proportion of traffic in all directions, gradually changes (from 0.7 times to 2.0 times) its total flow for simulation, and outputs the average queue length and average delay as evaluation indicators, comparing the roundabout three kinds of control methods are analyzed to obtain the applicability of various control methods under different flow rates. The original flow is shown in Table I, and the proportion of the total flow changed is shown in Table III.

B. Simulation signal timing

The radius of the island r_0 =31m， α =135° .If the width of the lane is 3.5m, then w =12m. When the flow rate is 6456pcu/h, two - step left control's c_0 = 80s, c_c = 102s, so the optimal cycle is c = 102s.

According to formula (4), the capacity of a left-turn lane is 24 vehicles, and the average time interval between the two vehicles before and after passing through the parking line is 2s. The difference between the start time of the green light of the upper phase loop and the green light of the phase-inlet lane is 12s. At the same time, left-turning vehicles waiting to travel in the ring road will not be in conflict with the next-phase forward-traveling vehicles. In order to simplify the roundabout signal, the signals of the second parking line are only set to red light and green light, and the signal timing is shown in Fig. 4.

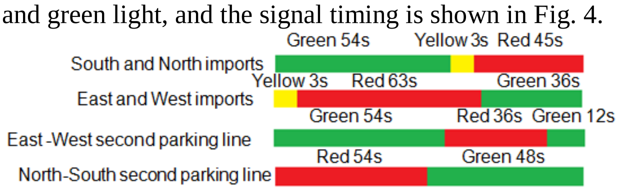

Figure. 4 Signal timing

V. Results and Evaluation Analysis

This article uses VISSIM 5.2, output average queue length and average delay as evaluation indicators, and lists the Shuma Square simulation data under different traffic. The results are shown in Table III and Fig. 5.

According to the standards for the service level of intersections in the Urban Road Engineering Design Criteria (CJJ37-2012), as shown in Table II, the service level of each intersection is evaluated.

TABLE II. Signal Intersection Service Levels

Service Level / index	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Control delay(s/veh)	＜30	30~50	50~60	＞60
Degree of load	＜0.6	0.6~0.8	0.8~0.9	＞0.9
The length of queue(m)	＜30	30~80	80~100	＞100

TABLE III. Simulation Evaluation Index

Total flow	**Priority control**				**Each phase for entrance**				**Two - step left control**			
pcu/h	**Average delay(s)**	**Average queue(m)**	**Degree of load**	**Service Level**	**Average delay(s)**	**Average queue(m)**	**Degree of load**	**Service Level**	**Average delay(s)**	**Average queue(m)**	**Degree of load**	**Service Level**
2302	1.70	0.80	0.17	Level 1	2.10	1.28	0.21	Level 1	2.60	1.37	0.26	Level 1
2630	3.10	1.75	0.25	Level 1	4.30	2.30	0.29	Level 1	5.30	3.13	0.31	Level 1
2959	4.60	2.39	0.30	Level 1	6.70	4.90	0.36	Level 1	7.40	6.52	0.45	Level 1
3228	7.80	4.70	0.32	Level 1	9.50	5.75	0.42	Level 1	10.30	8.50	0.49	Level 1
3551	16.70	14.25	0.39	Level 1	22.10	17.00	0.47	Level 1	23.40	20.25	0.52	Level 1
3874	25.70	22.75	0.52	Level 1	28.20	26.25	0.53	Level 1	28.90	28.25	0.63	Level 2
4196	26.80	27.00	0.67	Level 2	30.00	29.75	0.59	Level 1	31.00	29.75	0.69	Level 2

4519	31.55	38.75	0.79	Level 2	31.60	33.50	0.68	Level 2	35.30	36.00	0.72	Level 2
4842	41.40	41.75	0.82	Level 3	35.40	37.00	0.72	Level 2	38.60	40.25	0.74	Level 2
5156	44.60	44.25	0.86	Level 3	34.90	41.00	0.81	Level 3	41.90	42.50	0.78	Level 2
5488	50.50	48.50	0.89	Level 3	46.20	42.50	0.84	Level 3	45.20	43.70	0.81	Level 3
5810	68.10	57.00	0.96	Level 4	58.10	50.00	0.86	Level 3	49.30	45.50	0.84	Level 3
6133	74.00	62.00	1.18	Level 4	68.10	53.50	0.91	Level 3	53.50	49.75	0.87	Level 3
6456	89.00	70.00	1.39	Level 4	75.00	60.75	0.97	Level 4	59.90	54.50	0.90	Level 3

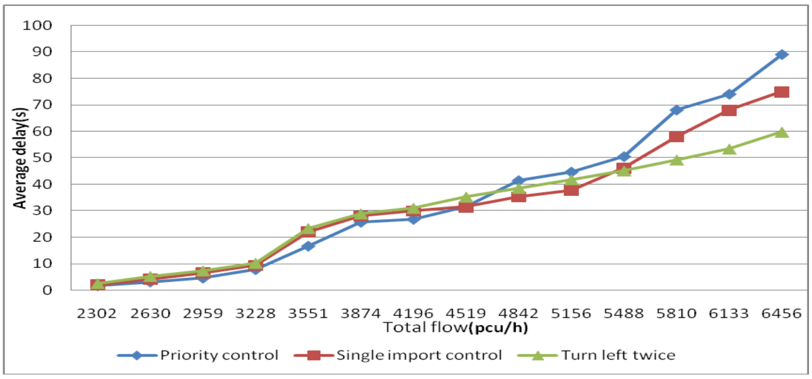

Figure 5. Comparison of average delay

This article through the simulation experiment, combined with the evaluation index can draw the following conclusions:

(1) When the traffic is less than the 3228pcu/h, the delays and queue lengths of the three control modes are all low, and the service level is one level, but the setting of the priority control mode is the most simple and convenient.

(2) At the present stage, the traffic flow at the Shuma Square roundabout is relatively small. When the flow rate is less than about 4200pcu/h, the priority control mode is very smooth. It is a first-class service level, and the average delay and average queue length are both less than the other signal control modes. When the flow rate is 3800pcu/h, the two signal control methods have reached the second-level service level, and the priority control method is optimal.

(3) When the flow rate is 4200-5500pcu/h, it can be seen from the figure that the delays and queuing lengths of priority control roundabouts are obviously biger than the two signal control modes, and the service level reaches three levels; at this time, the each phase for entrance control method is similar to the two - step left control mode. And it is the same as the secondary service level, but it is still better than the latter. Therefore, the each phase for entrance control method is best in this flow range.

(4) When the flow rate is biger than 5500pcu/h, it can be seen that the priority control roundabouts have a delay and queuing increases drastically, and the service level reaches level 4. It can also be seen from VISSIM that multiple intersections are locked. At this time, the two - step left control mode optimization effect is more significant. And the queue length, delay, and saturation rate are lower than that of the each phase for entrance control method. At this time, it is most suitable to use the two - step left control method.

VI. Conclusion

The article uses VISSIM to simulate the roundabout at Dalian Shuma Square, and gradually increase the flow rate on the basic data to obtain the applicable range of the three control modes under different traffic. When the flow is greater than 5500pcu/h, two - step left control method improved the traffic capacity of the roundabout because of its traffic flow separation mode. The Shuma Square roundabout can adopt different control methods according to different traffic flow. Two - step left control method is adopted in the morning and evening peaks; priority control methods are used in flat hump period, which can effectively improve the service level of the roundabout. However, the impact of non-motor vehicles was neglected during the experiment, and the simulation data was based on a survey and had certain limitations. In the future, data collection work at different time intervals and different roundabouts should also be conducted for in-depth discussion and research, thus giving general applicability of roundabout control methods.

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