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Simulation Research on Shifted Left-Turn Intersection Based on Secondary Signal Control

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Abstract: In urban roads, intersections are gathering places where traffic flows converge, turn, and evacuate, and are key points of urban road traffic. At the same time, it is also the bottleneck of the urban road network, the place where accidents happen frequently and the origin of traffic congestion. Reasonable optimization design of road intersections plays a particularly critical role in improving vehicle traffic efficiency, reducing delays, and ensuring smooth vehicle traffic. Based on the fact that left-turning vehicles are the main reason for increasing conflict points, in order to reduce the conflict between left-turning and straight-going and right-turning vehicles, this paper adopts a shifted left-turn method to eliminate the conflicting points with the oncoming straight-going vehicle, and use four-phase signal Timing becomes a two-phase signal timing. At the same time, a secondary signal timing design is carried out for the shifted left-turning vehicle. The signal timing adopts the overlap time under two phases, and does not increase the total signal cycle time, so as to avoid the conflict point of the left-turning vehicle and the road vehicle when turning. On this basis, an intersection model that integrates lane markings and canalization, left-turn waiting area, and signal timing schemes is proposed. Finally, a certain intersection is selected, and relevant evaluation indicators such as average delay of vehicles and maximum queue length are obtained through Vissim simulation. The research results show that the setting of a shifted left-turn intersection controlled by the secondary signal can significantly improve the traffic capacity of the intersection. Compared with the original intersection, the traffic capacity of the designed intersection has been significantly improved.
Keywords: Secondary signal control, shift left, Vissim simulation, traffic design.

1. INTRODUCTION

In recent years, as the number of vehicles has increased, road traffic has increased significantly, and the design of intersections has gradually been unable to meet the traffic demand. Due to inadequate design of many intersections, there is a lack of canalization facilities and unreasonable traffic organization at the intersections. The traffic flow inside the intersection is chaotic and becomes a frequent traffic jam during peak periods. To solve the congestion problem at intersections, it is undoubtedly necessary to start with improving the capacity and efficiency of the intersection. Scholars at home and abroad mainly start with the number of left-turn lanes at the intersection and widen the entrance lanes, and improve the traffic capacity of the intersection by improving the utilization of space resources at the intersection [1-3]. Zhang et al. used the Vissim software to study the influence of the length of the left-turn lane widening at the intersection on the traffic capacity of the intersection [4]. Ma et al. proposed a method based on pre-signal control to improve the efficiency of left-turn traffic at an intersection [5]. Zhao Dongbin et al. studied the research and application of adaptive dynamic programming methods in urban road traffic signal control [6]. Helbing et al. studied the influence of signal timing schemes at signalized intersections, data survey time period, and lane group position on intersections, and found that signal timing schemes and investigations are among the factors affecting headway time. The impact of time period is small [7]. Zhou Jie et al. studied the headway of left-turning and U-turn vehicles, and analyzed the headway characteristics of left-turning and turning vehicles, and obtained the conclusion that the left-turning and U-turn vehicles affect the traffic capacity of signalized intersections [8]. Due to the early development of motorization, the research on left-turn traffic organization design in foreign countries is earlier than that in my country and has a wealth of ready results, including the principles and methods of setting up special left-turn lanes, capacity analysis procedures and methods, and channelized traffic design Methods etc. [9]. Based on previous research, left-turning vehicles are the main reason for increasing conflict points. In order to reduce the conflicts between left-turning and straight-going and right-turning vehicles, this paper adopts a shifted left-turn method to eliminate the conflicting points with oncoming straight-going vehicles. Four-phase signal timing becomes a two-phase signal timing. At the same time, the secondary signal timing design is carried out for the shifted left-turning vehicle. The signal timing adopts the overlap time under two phases, and does not increase the total signal cycle time, so as to avoid the conflict point of the left-turning vehicle and the road vehicle when turning.

2. SET UP A SHIFTED LEFT TURN SIGNALIZED INTERSECTION CONTROLLED BY THE SECONDARY SIGNAL

The basic form design of conventional intersections is shown in Figure 1 and Figure 2. It can be found that in a conventional four-phase signal-controlled intersection, each phase needs to be allocated a green light time, which will undoubtedly increase the signal cycle time, thereby affecting the traffic volume at the intersection, increasing the length of vehicle queues, and causing unnecessary time delays. Taking entrance direction 1 as an example, when the green light goes straight from north to south, as shown in Figure 1, the other three phases are all in a waiting state. In the same way, the other three phases are also in the waiting state when the east-west is going straight green.

To a certain extent, regular intersections have passed time layout, eliminating some conflicting points between vehicles, and also improving the safety of the intersection and the traffic volume to a certain extent. However, there are still conflicts between left-turn traffic and other traffic flows, and a special left-turn phase is needed to separate the traffic of other phases. This article attempts to set a shifted left turn at a conventional intersection, eliminate the time of each left turn phase, increase the green letter ratio of the entire intersection, further improve the traffic efficiency of the intersection, and reduce vehicle delays. The spatial layout of the shifted left-turn intersection is shown in Figure 3 and Figure 4. It can be found that when the vehicle enters the intersection, the vehicle will turn left and turn right into the rightmost lane according to the traffic warning signs. For right-turning vehicles, when they reach the right-turning exit, they will pass through the dedicated right-turning lane and exit the intersection to complete the right-turning vehicle. The whole cycle of right-turning vehicles is the green time. It can be seen in Figure 3 that the left-turning vehicle enters the left-turn waiting area and arrives at the secondary signal control point. When direction 1 and direction 3 go straight to the green light, direction 2 and direction 4 are in the red light state. Use direction 2 and direction 4 to wait for the red light time. There is no vehicle passing in this direction. At this time, the left turn vehicle enters the lane and passes the road . Through the secondary signal control, the conflict with the straight going in the direction is avoided, and the barrier-free traffic between the left turn, right turn and straight going in this direction is realized. Take entrance direction 1 as an example. In Fig. 3, when direction 1 goes straight to the green light phase, straight vehicles can pass through the intersection, left-turning vehicles enter the direction 2 entrance lane, and direction 1 green light ends, a cycle of left-turning vehicles basically drive in Direction 2 entrance lane. It can be seen from Figure 4 that these left-turning vehicles waiting at this time can immediately follow the straight-going vehicles in direction 2 to leave the intersection and complete a left turn. The whole process is the phase control of the signal number two.

3. CASE STUDY

The intersection of Baotou Street and South Xing'an Road in Hohhot is selected as a case. The intersection is Xing'an South Road in the north-south direction, and Baotou Street in the east-west direction. And each direction is a two-way traffic flow. The intersection is divided into 4 phases, the first phase is north-south straight, the second phase is east-west straight, the third phase is north-south left, and the fourth phase is east-west left.

3.1 Analysis of Intersection Status

Using the traffic flow during the morning rush hour (7:00-8:00) at the intersection of Baotou Street and South Xing’an Road, statistics can be used to obtain the traffic volume of each import, as shown in Table 1.

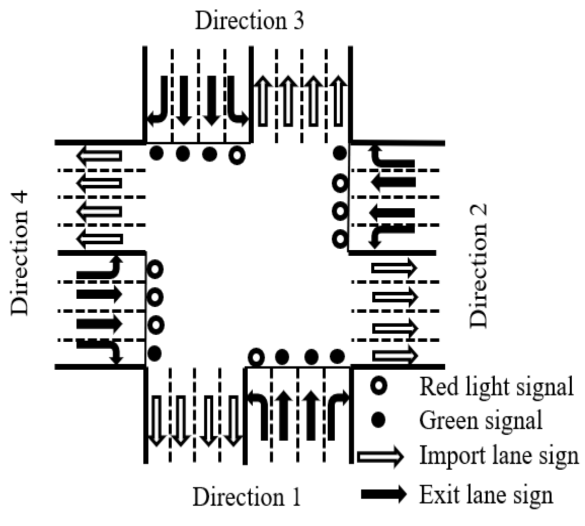

Fig. 1 Conventional intersection 1

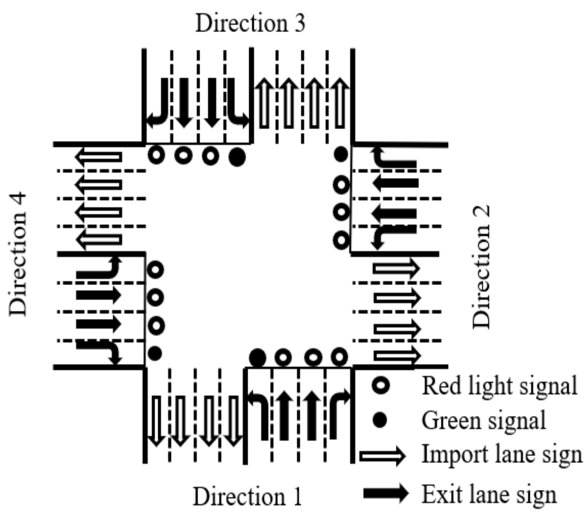

Fig. 2 Conventional intersection 2

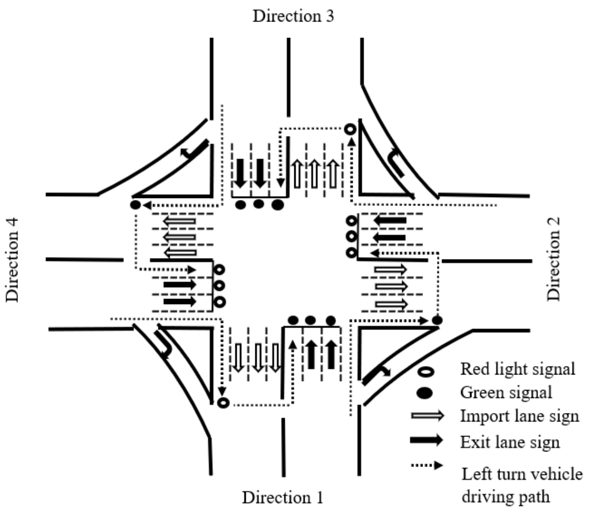

Fig. 3 Shift left turn at intersection 1

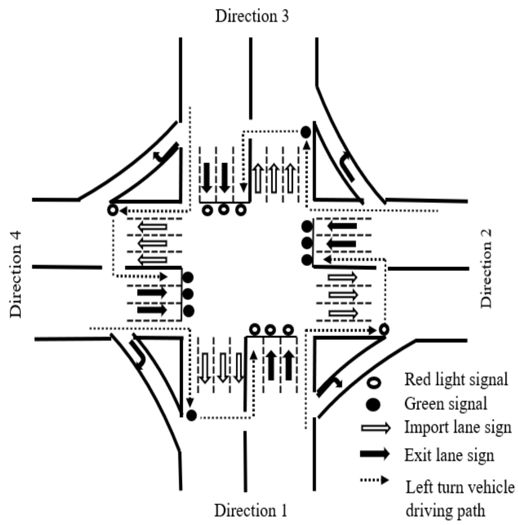

Fig. 4 Shift left turn at intersection 2

Table 1 Intersection morning rush hour (7:00-8:00) hourly traffic volume

Direction	Straight (pcu/h)	Turn left (pcu/h)	Turn right (pcu/h)	Total (pcu/h)
East Import	307	275	181	763
West Import	435	347	154	936
South Import	954	338	129	1421
North Import	824	274	284	1382

It can be seen from Table 1 that the traffic density per unit time at this intersection is relatively high, and the flow of north-south straight traffic is relatively large, and the left-turning vehicles at each entrance are basically the same. The current signal timing of the intersection is: Baotou Street and South Xing'an Road signalized intersection adopts four-phase signal timing control, the signal period is 125s, and the east-west direction is straight: green time 25s, yellow light time 3s, full red time 2s; east-west turn left Direction: green light time 30s, yellow light time 3s, full red time 2s; north-south straight direction: green light time 33s, yellow light time 3s, full red time 2s; north-south left turn direction: green light time 22s, yellow light time 3s, full red Time 2s. The signal timing is shown in Table 2.

Table 2 Signal timing

Serial number	Semaphore group	Red light end time(s)	Full red time(s)	Green light end time(s)	Yellow light time(s)
1	Straight from east to west (light set 1)	0	2	25	3
2	Turn left from east to west (light group 2)	30	2	60	3
3	Go straight from north to south (light group 3)	65	2	98	3
4	Turn left from north to south (light group 4)	103	2	125	3

Input the surveyed traffic volume data into Vissim for simulation operation, and then output the vissim simulation results to obtain the average annual vehicle delay, average queue length, average parking time, and maximum queue length of each entrance lane of the intersection. As shown in Table 3:

Table 3 Simulation results of the current situation of the intersection

Vehicle path	Average delay/s	Average queue length/m	Maximum queue length/m	Average parking time (number of times)/s
Turn left at the east entrance	43.57	19.78	85.22	1.13
Turn right at the east entrance	2.81	0	0	0.09
East import straight	44.42	19.78	39.63	0.84
West entrance turn left	50.77	36.91	104.14	0.94
West entrance turn right	0.26	0	0	0
West Import Straight	44.45	22.49	103.24	0.89
Turn left at the south entrance	45.06	12.46	84.25	1.1
South entrance, turn right	3.53	0	0	0.17
South import straight	38.59	24.48	37.82	0.8
North entrance turn left	37.68	19.09	109.47	0.9
North entrance turn right	1.97	0	0	0.04
North import straight	40.23	26.33	83.59	0.83

3.2 Shift left turn optimization design method

The four directions of the intersection are set to shift to the left at the same time, and the channelization design is shown in Figure 5.

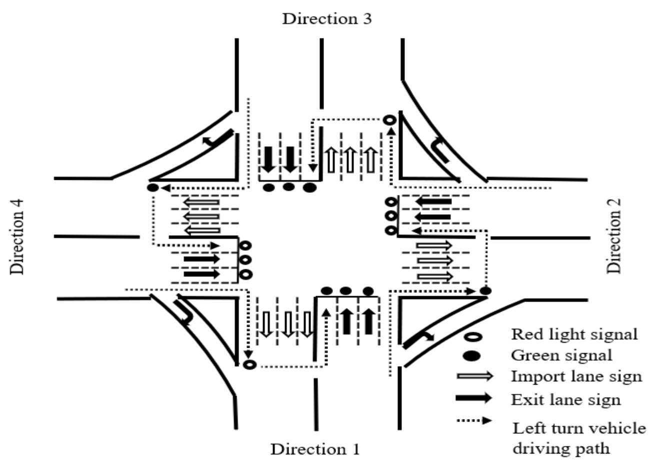

Fig. 5 Shift left turn channelization design drawing

Diversion lines for left-turning vehicles and straight-going vehicles are set before the entrance of the intersection, which is conducive to the driver's advance judgment and improves the safety rate of the intersection.

Set a secondary signal before the left-turn vehicle parking line to avoid unnecessary conflicts with vehicles leaving the intersection.

On the basis of ensuring that the turning radius is met, the DLT traffic diversion line and the speed limit sign shall be set at the turning point of the left-turning vehicle to achieve the purpose of safe driving.

3.3 Determine signal timing

The calculation methods of signal timing mainly include the WEBSTER method in the United Kingdom, the HCM method in the United States and the ARRB method in Australia. In my country, there are the parking line method and the conflict point method. The method in this article mainly uses the British WEBSTER method.

According to the intersection channelization plan, the intersection signal is determined to be two-phase. The first phase is the east-west entrance going straight, and the second phase is the north-south entrance going straight. A left-turning vehicle enters a straight lane in each direction and then follows a straight vehicle in each direction to pass.

To determine the optimal cycle time, first determine the cycle loss time, where the start-up loss time is 3s, the yellow light time is 3s, and the green light time interval (that is, the yellow light time plus the full red time, the general yellow light time is 3s, the full red time is 2s) Is 5s. According to Webster’s formula, the loss time L per cycle is 10s. Then determine the maximum flow ratio Y of each phase within the period length. The maximum saturation Y of each phase within the period length can be determined according to the basic saturation flow of each entrance lane. The basic saturation flow S_hi when each type of entrance lane has its own dedicated phase, the value in Table 4 can be used:

Table 4 Basic saturated flow of various lanes (pcu/h)

Lane	S_{hi}
Straight lane	1400-2000，average 1650
Right turn lane	1550
Left turn lane	1300-1800，average 1550

$$x_i = \frac{q_i}{NS_{bi}}$$

In the formula, x_i is the saturation of each lane; q_i is the actual traffic volume of each lane per hour; S_{bi} is the basic saturated flow of the entrance lane; N is the number of entrance lanes.

According to Table 4 and the above formula, determine the saturation of each lane of the different paths of each entrance, and finally get the maximum saturation of 0.615. Using Webster's formula, the period is 55s. The green light time of signal light group 1 is 17s, the yellow light time is 3s, the green light time of signal light group 2 is 27s, the yellow light time is 3s, and the full red time is 2s. The signal timing parameters are shown in Table 5.

Table 5 Intersection timing parameters

Serial number	Semaphore group	Red light end time (s)	Full red time (s)	Green light end time (s)	Yellow light time (s)
1	Semaphore group 1	0	2	19	3
2	Semaphore group 2	23	2	52	3

3.4 Optimized design scheme Vissim simulation

Input the traffic volume data into Vissim for simulation operation, and then output the simulation results of vissim, the average annual vehicle delay, average queuing length, average parking time, and maximum queuing length of each entrance lane of the intersection can be obtained. As shown in Table 6:

Table 6 Optimize simulation result data

Vehicle path	Average delay/s	Average queue length/m	Maximum queue length/m	Average parking time (number of times)/s
Turn left at the east entrance	12.12	2.17	25.64	0.77
Turn right at the east entrance	0.06	0	0	0
East import straight	10.79	1.88	12.2	0.51
West entrance turn left	12.10	3.44	34.15	0.58
West entrance turn right	0.03	0	0	0
West Import Straight	12.80	3.2	19.60	0.56
Turn left at the south entrance	14.50	9.68	68.81	0.56
South entrance, turn right	19.29	9.68	68.81	0.79
South import straight	8.54	4.65	31.98	0.43
North entrance turn left	16.44	5.76	33.98	0.83
North entrance turn right	0.06	0	0	0
North import straight	7.81	3.93	34.37	0.38

3.5 Comparative analysis of Vissim simulation results

Compare the current simulation results of the intersection with the simulation results of the optimized plan, as shown in Figure 6, Figure 7, Figure 8, and Figure 9.

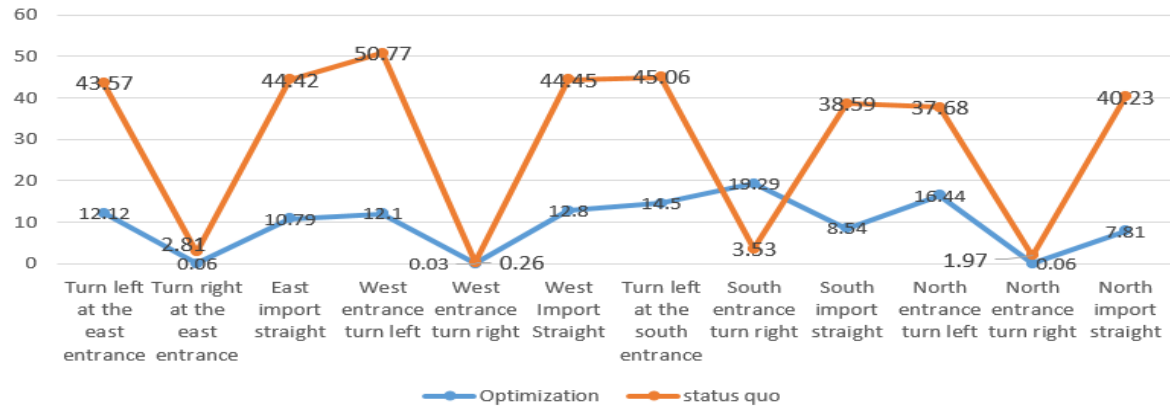

Fig. 6 Average delay comparison chart

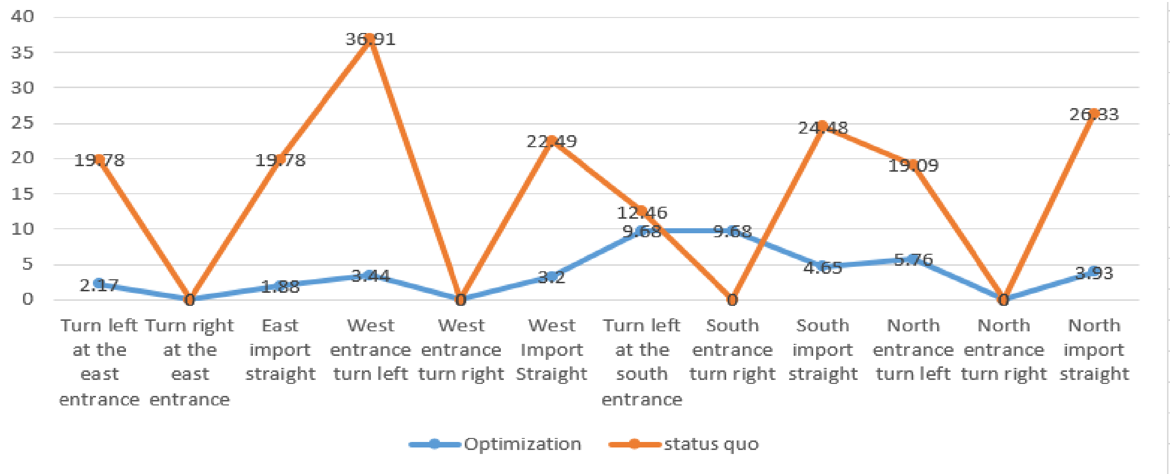

Fig. 7 Average queue length comparison chart

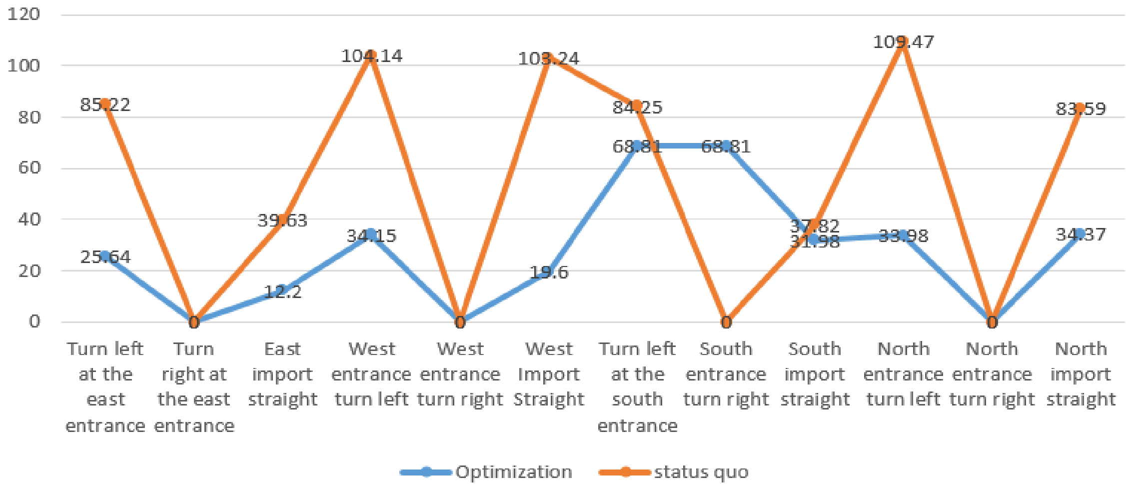

Fig. 8 Maximum queue length comparison chart

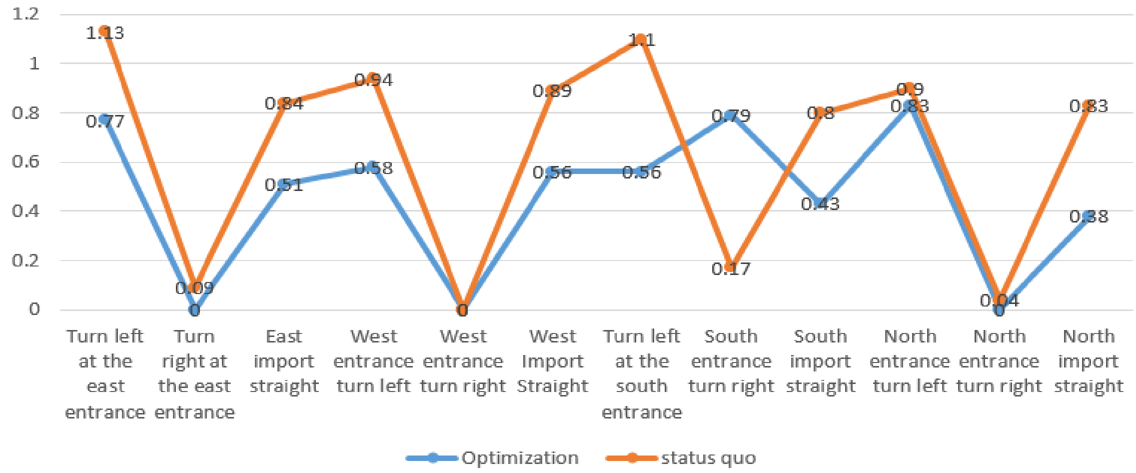

Fig. 9 Average parking time comparison chart

The total average delay at this intersection before optimization is 29.4s, the total average queue length is 15.11m, and the total average maximum queue length is 53.9m. The total average parking time is 0.64 times/s. After using the channelization design scheme, the total average delay is 9.5s, the average queue length is 3.7m, the average maximum queue length is 27.5, and the average parking time is 0.45 times/s, which are reduced by 67.7%, respectively. 75.5%, 49% and 30%. It can be seen that the shifted left-turn design controlled by the secondary signal can improve the traffic capacity and operation efficiency of the intersection, and is an effective measure to alleviate the congestion at the urban intersection.

4. CONCLUSION

This article uses the shift left turn controlled by the secondary signal to optimize the design of the intersection. The method of shift left turn is to borrow the original right turn lane at the intersection, transfer the conflict point between the left turn and the straight traffic to the road section, and again Use the secondary signal control to eliminate the conflict point between the left-turning vehicle and the straight-going vehicle on the road section. In the case of long-term unsaturation at the intersection, the improvement of traffic capacity at this time is of little significance, and it may be shifted to the left and will cause additional delays. Subsequent research needs to focus on various influencing factors that affect the setting of shifted left-turn intersections, as well as practical application effects.

REFERENCES

[1]Jamie W. Hurley. Utilization of Auxiliary Through Lanes at Signalized Intersections with Downstream Lane Reductions[J]. Transportation Research Record,1997,1572(1).
[2]Jamie W. Hurley. Utilization of Auxiliary Through Lanes at Signalized Intersections with Downstream Lane Reductions[J]. Transportation Research Record,1997,1572(1).
[3] Wu Mengqian, Yuan Li, Cui Erjuan, Zhou Zhijiang. Safety design of harbor-style left-turn lanes at level intersections[J]. Highway Traffic Technology, 2012(02):118-121.
[4]Yunlong Zhang,Jiaxin Tong. Modeling Left-Turn Blockage and Capacity at Signalized Intersection with Short Left-Turn Bay[J]. Transportation Research Record,2008,2071(1).
[5]Wanjing Ma,Hanzhou Xie,Yue Liu,Larry Head,Zhenke Luo. Coordinated Optimization of Signal Timings for Intersection Approach with Presignals[J]. Transportation Research Record,2013,2355(1).
[6] Zhao Dongbin, Liu Derong, Yi Jianqiang. Overview of urban traffic signal optimization control methods based on adaptive dynamic programming[J]. Acta Automatica Sinica, 2009, 35(06): 676-681.

[7]Dirk Helbing. Collective phenomena and states in traffic and self-driven many-particle systems[J]. Computational Materials Science,2004,30(1).

[8]Zhou Jie. Research on traffic capacity and its influencing factors of left-turn lanes at signalized intersections of urban roads[D]. Beijing University of Technology, 2010.

[9] Liu Shupeng, Ma Jun. Research on U-turn Traffic Flow Organization Mode of Road Section[J]. Transportation System Engineering and Information, 2007(02): 124-128.