Study on Optimization of Traffic Dissolution around Large Supermarket

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Abstract

With the rapid development of social economy, the number of large supermarkets in the central area of cities has generally increased, and the traffic problems around large supermarkets have become increasingly prominent, which will become a common problem in urban traffic in China. The surrounding area of large supermarket has the characteristics of large traffic attraction, high daily travel rate, unbalanced traffic supply and demand, etc., which is prone to traffic accidents. In this paper, a large supermarket in Shangqiu City as the research object, through the optimization design of its surrounding intersections and vissim traffic simulation, the internal and external traffic organization program evaluation, and to improve the reasonable situation of the large supermarket surrounding traffic to provide appropriate reference recommendations.

Keywords

Urban traffic; Traffic deconstruction; Traffic organization; supermarket surrounding.

1. INTRODUCTION

In recent years, with the general improvement of people's living standards, the number of private cars in China has grown rapidly, and the way of self-driving for residents to purchase goods is increasing. However, most supermarkets are located in the central area of the city, with large traffic flow and people flow, limited parking spaces, insufficient traffic diversion and frequent traffic accidents, which often lead to traffic congestion and parking difficulties around supermarkets. There are many characteristics around the large supermarket, such as large amount of traffic attraction, high daily travel rate, unbalanced traffic supply and demand, etc. Experience shows that one of the important reasons for traffic congestion around large supermarkets is the imbalance between supply and demand of traffic conditions around supermarkets. However, large supermarkets are located in the central area of the city, and the surrounding land resources are particularly tight, so it is impossible to expand the traffic infrastructure without restriction. Instead, the existing traffic infrastructure should be excavated to make the best use of it. Therefore, through the study of this topic, so as to provide a better urban traffic environment for the residents around the supermarket, and comprehensively improve the service level of the road traffic around the supermarket in the city center. Achieve the goal of good road traffic operation around large supermarkets.

The development of transportation depends on and serves the people. Therefore, the development direction of the traffic should continue to develop in the direction of humanization, so that traffic management and planning departments to consider more places to serve the people, through this paper on the large supermarket surrounding traffic optimization research and practice, hope to be able to make the traffic department for this kind of distribution center area attention.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

2. RESEARCH STATUS AT HOME AND ABROAD

2.1. Current status of research abroad

From the development of traffic engineering in foreign countries, the early research focus of business district is to strengthen the construction of road traffic infrastructure, improve the roads around business district, and enhance the service quality of roads.

In the early 1960s, German scholars put forward the idea of "Jinsen Cross", which built a commercial district on the urban rail system, and built a large number of public transport infrastructure and parking lots, making full use of the space resources of the road network and shortening the travel time[1].

Since the 1970s, research has begun to improve the utilization rate of the current transportation network, for example, the transportation system management TSM proposed by the United States; In the 1980s, traffic demand management TDM was put forward, and at the same time, the Access Management Committee was established in the United States to improve AM (Access Management) technology by comprehensively considering land use and economic analysis for the entrance and exit management of commercial entities.

In recent years, different countries have different understandings on the research of traffic relief around large traffic attraction sources. In the aspect of traffic organization strategy research, Christopher concluded in 1995 that the traffic congestion in urban business district can be reduced by creating internal circulation system and optimizing node design in some areas with large traffic flow, and the roads of different grades are classified and then combined to form a circular road network.

The parking search model proposed by Thompson R G and Thompson A J A in 1995 and the parking generation theory proposed by I.T.E established in the United States all play a certain guiding role in the parking allocation of large-scale traffic attraction buildings[2].

At the beginning of the 21st century, Urbia Company in the United States created a simulation model of the road network around the downtown area of Manhattan, and applied the dynamic traffic assignment principle to the micro-simulation of different functional areas.

Foreign scholars from the travel characteristics, parking demand, travel mode, travel distance, weather and other aspects of a comprehensive study. In 2008, Mueller Sevn et al. collected these factors and used multivariate logit method to establish a model, and determined that distance, large-scale traffic attraction source and policy attribute are the three major factors affecting travel behavior choice[3].

In 2019, Jin Cao, Monica Menendez and Rashid Waraich et al. quantitatively or qualitatively described the potential impact on traffic performance by discussing four parking policies: adjusting parking supply, adjusting parking time control, adopting dynamic parking charging and providing parking prediction [4].

The foreign related research mainly centers on the parking facilities around the business district, taking Germany and the United States as representatives, on the basis of a large number of investigations and analysis, the parking indicators reflecting the grade differentiation of urban key areas and large-scale traffic attraction buildings are formulated, which can provide reference for the traffic management and planning departments.

2.2. Domestic research status

For the large traffic attraction, domestic scholars also have some research, but according to the domestic data, domestic scholars often pay too much attention to the specific object of traffic problems and research methods, which often lack some systematic traffic organization and management methods. As one of the key traffic distribution centers in the city, the traffic congestion around the supermarket has gradually gained high social attention.

In 2007, Xu Lili analyzed from the perspective of consumption purchase decision, studied the choice probability and constructed Logit model[5], and estimated the operation efficiency of road traffic organization after adding VSM in Beijing City road network based on traffic organization optimization theory.

In 2008, Chen Jia put forward the method of one-way traffic organization to improve the contradiction between traffic demand and traffic supply in commercial district[6]; in 2008, Han Yuhe[7] analyzed the characteristics of large distribution centers and the demands of traffic demanders, and carried out certain traffic organization from aspects of reducing traffic pressure on surrounding roads during peak hours, implementing three-dimensional traffic, intensive and reasonable layout of parking facilities, etc.

In 2011, Rao Qiuli investigated the travel characteristics of traffic travelers in Dalian Central Business District through intention survey, and established a model to analyze the influence of travel time on the choice of private car or public transport travel behavior when traffic participants travel with complex chain[8].

In 2012, Liu Ziyu pointed out the traffic problems around the city hospital, and we can also find the traffic problems around the supermarket. Liu Ziyu believed that the traffic organization should be carried out in key urban areas from the aspects of pedestrian crossing, parking infrastructure and traffic guidance facilities at the intersections around the city hospital[9]; In 2012, Wu Zhiying believed that large distribution centers should focus on the layout of the road network around the distribution center, the management planning of parking infrastructure, the entrance and exit setting of the distribution center, Optimization design of public transport facilities around the distribution center [10].

In 2014, Yin Shaoning solved the blocking points around schools, hospitals, vegetable farms and markets with seven measures, circular traffic, comprehensive renovation and internal and external repair. In the 4+X working method, traffic organization optimization, traffic engineering reconstruction, traffic propaganda first and traffic management follow-up are taken as four constants to solve traffic congestion on four sides[11].

In 2018, Shi Congwei conducted quantitative analysis on Yuanyang Scenic Spot through fuzzy hierarchical evaluation method through the research on traffic distribution center of Yunnan mountainous tourist area, and put forward optimization suggestions for tourism traffic distribution and congestion relief[12].

In a word, domestic and foreign scholars have carried out systematic research on traffic organization management and evacuation optimization of large-scale distribution centers in cities, summarized and analyzed the problems existing in large-scale distribution centers, and obtained the characteristics of uneven distribution of time and space, obvious peak value and large flow, diverse traffic composition, obvious mixed traffic, low utilization rate of traffic space resources, contradiction between parking demand and parking supply, large traffic load at intersections and sections around distribution centers. This also provides a direction for this study.

3. INVESTIGATION AND OPTIMIZATION ANALYSIS OF PERIPHERAL INTERSECTIONS

There are two intersections around the supermarket, namely the intersection of Fengcheng Avenue and Central Street, and the intersection of Fengcheng Avenue and Hudong Road. This paper takes the intersection of Fengcheng Avenue and Zhongyang Street as an example.

3.1. Data analysis of the intersection of Fengcheng Avenue and Zhongyang Avenue

The survey content is the traffic flow during peak and even peak periods. The peak survey time is 7:30-8:30 in the morning. Since the opening time of large supermarkets is 9:30 in the

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

morning, in order to avoid large errors during even peak periods, 10:30-11:30 is selected as the average peak survey time. Due to the shortage of manpower, the video method was used to investigate the peak hour flow and the average peak hour flow. According to the different degree of road clearance occupied by different vehicles when driving, it is necessary to convert the peak hour flow of the investigation into vehicles and models. The corresponding vehicle type and conversion coefficient are shown in Table 1:

Table 1. Vehicle Model and Conversion Coefficient

Vehicle type	conversion coefficient
small car	1.0
Medium	1.5
Large car	2.0
Motorcycles	0.4

According to the conversion coefficient in Table 1, it can be concluded that the converted flow of vehicles in the morning peak of each approach road is as shown in Table 2

Table 2. Flow after Converting Morning Peak

import time period	East entrance			West entrance			South entrance			North entrance		
	Left	straight	Right	Left	straight	Right	Left	straight	Right	Left	straight	Right
7:30-7:40	37	29	42	22	21	85	72	85	39	39	95	23
7:40-7:50	26	37	45	25	23	98	67	99	35	39	112	28
7:50-8:00	41	35	46	26	19	102	70	76	40	44	131	24
8:00-8:10	29	29	38	25	26	95	70	86	41	45	97	23
8:10-8:20	36	30	46	31	27	79	77	91	33	42	102	21
8:20-8:30	34	32	50	29	20	96	74	80	36	43	126	27
Subtotal	203	192	267	158	136	555	430	517	224	252	663	146

According to the field investigation, the total signal cycle time at the intersection of Zhongyang Avenue and Fengcheng Avenue is 127s, phase 1 (Φ1) is the north-south straight right turn phase, phase 2 (Φ2) is the north-south left turn phase, phase 3 (Φ3) is the east-west straight right turn phase, and phase 4 (Φ4) is the east-west left turn phase.

3.2. Optimization Design of Intersection between Fengcheng Avenue and Zhongyang Street

The design hourly traffic volume of each entrance road and each turn of Fengcheng Avenue and Central Avenue can be obtained from Table 2, as shown in Table 3:

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

Table 3. Design hourly traffic volume

inlet direction	turn	design hourly traffic volume
East	Left	246
	straight	222
	Right	300
West	Left	186
	straight	162
	Right	612
South	Left	462
	straight	594
	Right	246
North	Left	270
	straight	786
	Right	168

The straight-through equivalent coefficient can be obtained by looking up the table, and the average straight-through equivalent of single lane can be obtained according to the straight-through equivalent coefficient, as shown in Table 4:

Table 4. Calculation of Straight Equivalent of Lane Group

inlet direction	turn	flow rate	straight-line equivalent coefficient	straight equivalent	straight-through equivalent of lane group	Average single lane straight equivalent
east	Left	246	1.05	258	258	258
	straight	222	1	222	582	291
	Right	300	1.2	360		
West	Left	186	1.05	195	195	195
	straight	162	1	162	896	298
	Right	612	1.2	734		
South	Left	462	1.05	485	485	485
	straight	594	1	594	916	305
	Right	246	1.31	322		
North	Left	270	1.05	283	283	283
	straight	786	1	785	1005	335
	Right	168	1.31	220		

According to the general principle of left-turn protection phase: The left-turn lane flow of the east, south and north entrances is greater than 200, so the left-turn protection phase shall be set at the three entrances. The left-turn lane at the west entrance q_{LT} =186 200, but 186*[(158+136+555)/3]=52638>50000, so the left-turn protection phase shall also be set at the west entrance.

Based on the above analysis, the phase design scheme of the intersection of Zhongyang Avenue and Fengcheng Avenue can be determined as follows: Phase 1 (Φ1) is the north-south left-turn phase, phase 2 (Φ2) is the north-south straight right-turn phase, phase 3 (Φ3) is the

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

east-west left-turn phase, and phase 4 (Φ4) is the east-west straight right-turn phase. The phase control diagram is shown in Figure 1:

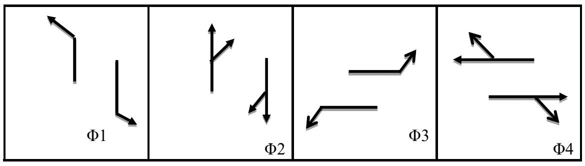

Figure 1. Phase Diagram of Intersection of Central Avenue and Fengcheng Avenue

(1) Determine the critical traffic flow and flow rate ratio. The critical flow rate ratio of each phase is as follows:

q_1=max{485,283}=485; q_2=max{305,335}=335;

q_3=max{258,195}=258; q_4 =max{291,298}=298

From the resulting saturation flow rate value of 1750veh/h, the critical flow rate ratios for each phase can be derived as shown in Table 5:

Table 5. Critical Flow Ratio

phase	flow ratio
phase one	0.277
Phase three	0.191
Phase three	0.147
phase four	0.170

$y_1 + y_2 + y_3 + y_4$=0.277+0.191+0.147+0.170=0.785< 0.9 The design requirements are met, and the next design can be carried out.

(2) Determine yellow light time and full red time

Calculate the duration of yellow light and the duration of full red light respectively by using Equations 1, 2 ,3.

$$A = t + \frac{v_{85}}{2a+19.6g} \tag{1}$$

Where: A-yellow light signal duration, s;

t-reaction time of driver, s, generally 1s;

v_{85} -85% of vehicle speed, or reasonable speed limit, m/s;

a-vehicle deceleration;

g-slope, expressed as a decimal;

19.6-2 times the acceleration of gravity.

$$r = \frac{P+L}{v_{15}} \tag{2}$$

Where: -Distance from stop line to far conflicting pedestrian crossing, m.

$$r = max\left(\frac{w+L}{v_{15}}, \frac{P}{v_{15}}\right) \tag{3}$$

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Where: -time duration of all-red signal, s;

w - distance from the stop line to the far opposing conflict lane, m;

L - The standard length of the car, usually 5~6m;

v_{15} -15% of vehicle speed, m/s;

P - Distance from stop line to far conflicting pedestrian crossing, m.

The design speed limit of 40km/h shall be adopted for the speed of east-west approach lane and the design speed limit of 40km/h shall be adopted for the speed of north-south approach lane. Since the east-west approach has the same speed limit as the north-south approach, it has the same yellow light duration. The calculation results are as follows:

$$A=1.0+40/3.6*2*3=2.90s$$

For convenience of timing, the duration of yellow light is rounded, A=3.0s

Because pedestrian crossing shall be considered, and pedestrian crossing traffic flow is medium, and the full red time is related to the width of intersection road, therefore, the full red time of Phase 1 and Phase 2 is different from that of Phase 3 and Phase 4, which shall be calculated separately. The specific calculation process is as follows:

$$r_{1,2}=\max[(21.5+5)/11.1，23.5/11.1]=2.38s$$

$$r_{3,4}=\max[(18.5+5)/11.1，18.5/11.1]=2.11s$$

where 5m is the average vehicle length. For convenience of timing, the full red duration of phase I and phase II is taken as an integer of 2s, and the full red duration of phase III and phase IV is taken as an integer of 2s.

Therefore, the green interval for each phase is:

$$I_1 =A+r_1 =3.0+2.0=5.0s$$

$$I_2 =A+r_2 =3.0+2.0=5.0s$$

$$I_1 =A+r_3 =3.0+2.0=5.0s$$

$$I_1 =A+r_4 =3.0+2.0=5.0s$$

(3) Determine signal loss time

The signal loss time of one cycle consists of the start-up loss of all phases and the full red time. The start-up loss is taken as 3s, so the signal loss of each phase is as follows:

$$L_{1,2}=3.0+2.0=5.0s$$

$$L_{3,4}=3.0+2.0=5.0s$$

The total signal loss for one cycle is:

$$L = L_1 + L_2 + L_3 + L_4=5+5+5+5=20s$$

(4) Determine the optimal signal cycle length

The method for designing the signal period according to the saturation control target of the intersection in peak hours uses the signal period formula, and the signal period of the intersection is:

$$C_0 =1.5*20+5/1-0.785=162.8$$

For ease of control, the calculation period is rounded, and the signal period length is C=163s.

(5) Allocation of green time

According to Equation 4, the effective green time for each phase is:

$$g_{E,j} = (C - L)\frac{y_j}{Y} \tag{4}$$

Where: --effective green time of phase i, s;

C --Cycle duration, s;

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

L --Total signal loss time, s;

y_i - Phase flow ratio;

Y --Sum of flow ratio.

From Equation 2-4, $g_{E,1}$ =50.4s;$g_{E,2}$ =34.8s; $g_{E,3}$ =26.8s; $g_{E,4}$ =31.0s

According to Equation 5, calculate the green light display time of each phase and round it to obtain:

$$g_j = g_{E,j} + l_j - A_j \tag{5}$$

$g_1=g_{E,1} +L_1-A_1 =50.4+3-3=50.4\approx50s$
$g_2=g_{E,2} +L_2-A_2 =34.8+3-3=34.8\approx35s$
$g_3=g_{E,3} +L_3-A_3 =26.8+3-3=26.8\approx27s$
$g_4=g_{E,4} +L_4-A_4 =31.0+3-3=31.0\approx31s$

In order to avoid errors in the rounding process of green light display time, accumulate the green light display time, yellow light time and full red time, and check whether they are equal to the cycle length. The test results meet the requirements, and the next step of design is entered. The total duration of the yellow light is 12 seconds and the total duration of the red light is8seconds. Add up to c=50+35+27+31+12+8=163s=C, so proceed to the next design.

(6) Pedestrian crossing inspection

During Phase 2 and Phase 4, there is pedestrian crossing demand, therefore, it is necessary to verify the green light display time of Phase 2 and Phase 4, and calculate the shortest green light display time meeting pedestrian crossing demand by using Equation 6, and the results are as foll

$$g_{min} = 7 + \frac{L_P}{v_P} - I \tag{6}$$

Where: -minimum green time, s;

L_P - pedestrian crossing length, m;

v_p - Pedestrian crossing speed, m/s;

I - green interval, s.

The calculation results are as follows:

Minimum green light display time for pedestrian crossing in phase 2 g_{min}=7+(25.6/1.2)-5 = 23s<g_2

Minimum green light display time for pedestrian crossing in phase 4 g_{min}=7+(38.9/1.2)-5 = 34s>g_4

According to the calculation results, the green light display time of Phase 2 can meet the minimum green light display time required by pedestrians crossing the street, while the green light display time of Phase 4 cannot meet the minimum green light display time required by pedestrians crossing the street. Therefore, it is necessary to carry out secondary pedestrian crossing on this phase and set pedestrian crossing safety island in the middle.

Another intersection of large supermarket can be optimized according to the same steps in this paper.

4. TRAFFIC ORGANIZATION SIMULATION AND SCHEME EVALUATION OF INTERSECTION AROUND3 LARGE SUPERMARKET

4.1. Simulation of Traffic Organization at Large Supermarket Intersection

Vissim simulation software can simulate the operation of urban road traffic. The simulation steps of the external traffic organization of the large supermarket are as follows:

1. Import background image

The selection of background image can be divided into two categories, namely satellite image and CAD image. Select the CAD image drawn in advance to import.

2. Draw the road section

Before drawing the road section, first set the scale, input the lane width value in the background image into the scale option, and then draw the road section in the corresponding position on the background image. When drawing the transition section section and the intersection vehicle running path, the method of connecting the road section shall be adopted, especially when drawing the intersection vehicle running path, the turning radius of the intersection shall be input at the position of the spline curve.

3. Set the vehicle path

This step is extremely important, especially on roads with transitions, where the number of lanes increases as the transition unfolds, and where the vehicle has to choose the correct trajectory to enter the lane, so be sure to see the location of the lane and enter the actual relative vehicle when setting the vehicle path.

4. Edit signal controller

The signal lamp is set at the stop line of each lane. After the signal timing optimization, the two intersections are controlled by four-phase signal. The green and yellow light time of each phase is input according to the signal lamp optimization timing scheme. The signal timing of the intersection between Central Avenue and Fengcheng Avenue is shown in Figure 2:

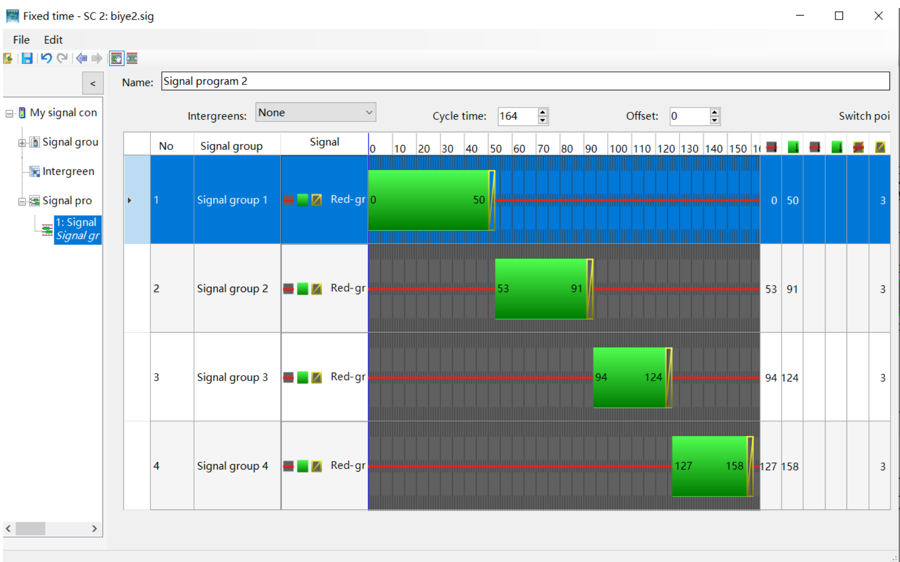

Figure 2. Signal Timing at the Intersection of Central Avenue and Fengcheng Avenue

Signal timing at the intersection of Hudong Road and Fengcheng Avenue is shown in Figure 3:

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

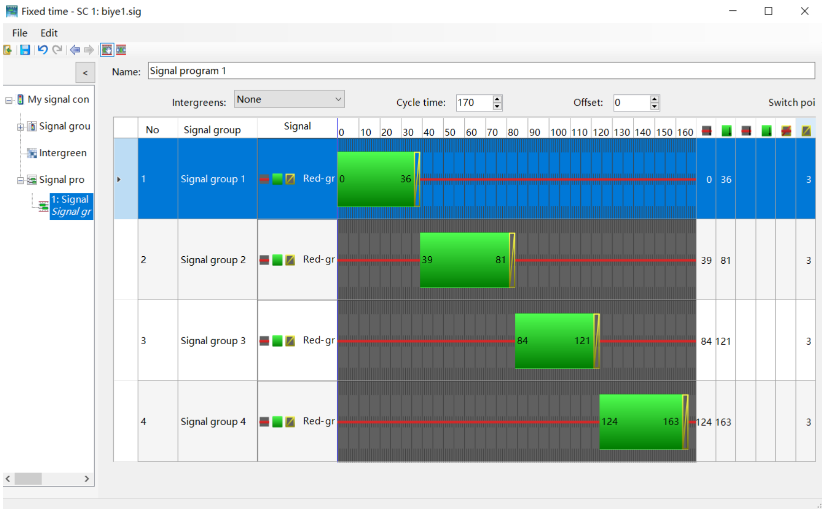

Figure 3. Signal Timing at the Intersection of Hudong Road and Fengcheng Avenue

5. Enter the traffic of the road section

The traffic flow of each approach road is input one by one according to the measured peak hour flow.

6. Simulation operation

4.2. Evaluation on Traffic Organization Scheme of Large Supermarket Intersection

Taking the intersection of Zhongyang Street and Fengcheng Avenue as an example, the current data of the intersection of Zhongyang Street and Fengcheng Avenue are input for simulation, then the optimized data of the intersection are input for simulation, and finally the results of the two simulations are evaluated and analyzed.

In the evaluation of large supermarket intersection traffic organization program needs to compare the relevant parameters, this paper mainly selected the average queue length, parking times and intersection delay of these three parameters to analyze the large supermarket external traffic organization optimization program.

1. Average queue length

After the optimization scheme of the intersection of Zhongyang Avenue and Fengcheng Avenue is simulated and operated in Vissim simulation, the queue length comparison table between the intersection status and the simulation scheme is shown in Table 6:

Table 6. Queue Length Comparison Table

entrance way	direction	Current situation	After optimization
		average queue length	average queue length
east	Left	19	9
	straight	21	12
	Right	0	0
South	Left	22	13
	straight	32	19
	Right	0	0
West	Left	12	10
	straight	18	15
	Right	0	0
North	Left	23	18
	straight	26	20
	Right	0	0

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

2. Parking times

The comparison table between the current situation of intersection and the number of stops in the simulation scheme is shown in Table 7:

Table 7. Comparison Table of Parking Times

entrance way	direction	Current situation	After optimization
		Number of stops	Number of stops
east	Left	24	20
	straight	26	23
	Right	0	0
South	Left	34	30
	straight	38	32
	Right	0	0
West	Left	26	19
	straight	30	32
	Right	0	0
North	Left	42	36
	straight	48	42
	Right	0	0

It can be seen from Table 6 and Table 7 that, in a simulation cycle, the average queue length and the number of stops at the south entrance and the north entrance have a trend of obvious reduction after optimization, which may be the result of signal green time distribution. The green time after optimization is longer than that before optimization, which makes the vehicles at the two entrances have more time to pass through the intersection, reducing the queue length and the number of stops.

From the above two parameters comparative analysis, the intersection in the optimization of the average queue length, parking times, basically lower than the status quo, which shows that the external traffic environment of large supermarkets has been improved, large supermarkets around the intersection of the congestion situation has been improved, intersection traffic efficiency and service level has been improved.

ACKNOWLEDGMENTS

This paper analyzes the status of the intersection around the supermarket, through the survey data on the intersection of the best signal timing and traffic organization design, in the signal timing through the intersection data design phase and the phase signal cycle, so as to determine the best signal cycle, reduce the intersection of vehicle delay time. In the aspect of intersection traffic organization, through the design of four phases, the traffic conflict points at the intersection are reduced, and the safety guarantee is provided for pedestrians crossing the street.

And through the Vissim simulation software to optimize the two intersections after the simulation operation and optimization evaluation, the results show that through the optimization design, the two intersections around the supermarket in the peak period significantly reduce the traffic congestion phenomenon.

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ISSN: 2472-3703 DOI: 10.6911/WSRJ.202309_9(9).0018

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