Optimization Design and Simulation Analysis of Traffic Organization in Road Intersection

Yanmei Wang*, Xiaotong Sun, Yaqi Fu, Jiahui Yang, Hailin Lu

Department of Smart Transportation, Anhui Sanlian University, Hefei, Anhui, 230601, China
*Yanmei Wang’s e-mail: 417087427@qq.com
Xiaotong Sun’s e-mail:2719056603 @qq.com
Yaqi Fu’s e-mail:2961875813 @qq.com
Jiahui Yang’s e-mail:3014526504 @qq.com
Hailin Lu’s e-mail:1332931904@qq.com

Abstract. As the process of city is being developed constantly as well as more and more people own cars , the problem of traffic jam on roads becomes much worse ,which will cause the decline of the performance of road services. As important components of urban roads, intersections play an important role in determining the capacity of urban road systems. Improving the flow at intersections and alleviating delay caused by traffic jams is one of the main ways to solve the problems in urban transport.The research object is the crossing of Jinzhai South Road and Zipeng Road in Hefei city. Based on the field survey data, the road traffic flow characteristics and traffic light time plan are studied at the morning peak hour(7:30~8:30).assessing straight-through lane, left-turn lane, and rightturn lane throughput and saturation.Results show high saturation on the south entry straight-through and left-turn lanes,meaning that the amount of traffic exceeds its capacity.Based on the real traffic condition - especially the congestion status at the rush hour, we have analyzed the reasons leading to the congestion; We also provided some improvement suggestions about traffic flow arrangement as well as signal control timing; According to VISIM simulation results, it can reduce 11.39% of total vehicle delay.-10.99% of the max queue length,-15.36% of the avg vehicle delays,-18.47% of the static parking delays and -8.86% of the parking frequency.The increase in the total flow at the intersection is substantial and can be considered as an important clue to guide further research on adaptive control of traffic signals.

Keywords: intersection; traffic simulation; optimization

1 Introduction

With the increasing prevalence of private vehicles and urban population growth,demand for urban transportation services continues to rise,leading to escalating road congestion and safety concerns.As critical nodes in urban road networks, intersections have become key targets for traffic flow optimization.Numerous domestic and international

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scholars have conducted extensive research on intersectiontraffic management systems.Studies demonstrate that installing ramp flow control devices at merging areas significantly reduces overall traffic delays,decreases vehicle stop frequency,and enhances average travel speeds[1].The study proposes integrating connected vehicle trajectory data with open-source OpenStreetMap data to map the central locations and surrounding areas of intersections,therebyenabling accurate evaluation of traffic light operational performance[2].The study developed a real-time, precise model capable of detecting traffic congestion conditions and allocating vehicle flow through dynamic signal control algorithms, thereby preventing vehicle starvation or gridlock[3].The research examined the impact of SOA algorithms (self-organizing algorithms) and PAA algorithms (phaseallocation algorithms) on signal control effectiveness regarding detection range[4].A study proposing dedicated motorcycle lanes in urban road networks found that while reducing overall vehicle throughput efficiency, these lanes significantly improve motorcycle traffic order and road safety[5].The study introduced a network model incorporating traffic routers that dynamically adjust signal phasesto mitigate congestion in real time[6].A fully scalable, decentralized multi-agent reinforcement learning algorithm was proposed for adaptive signal control in complex urban traffic networks[7].This paper used deep reinforcement learning technology to design a smart controller which can effectively adjust the traffic lights as well as the speed of the vehicles waiting at the intersection according to the current situation in order to achieve optimal traffic conditions[8].A traffic signal control method based on stochastic model predictive control was proposed, which incorporates uncertainty in traffic model parameters and proves applicable to urban traffic networks[9].The study developed a link traffic model to estimate signal delay variations under stochastic driving demand conditions[10].It proposed a coordinated control method for traffic signal management and vehicle speed optimization in connected autonomous vehicles, simultaneously optimizing signal timing schemes and vehicle trajectories[11].A green driving control strategy for signalized intersections with multi-level variable speed limits was introduced, effectively reducing vehicle delays while decreasing fuel consumption and pollutant emissions[12].A dynamic traffic light optimization strategy based on the intersection of poor lane-outside conditions is proposed to construct a basic intersection signal time plan, which can be used as an effective way to reduce the average delay of vehicles through the intersection and minimize the number of collisions[13].A fuzzy control-based optimization strategy for signal timing at oversaturated intersections was proposed, combining fuzzy control theory to alleviate congestion through extended green light durations [14].Statistical analysis and simulations revealed a traffic capacity calculation method for intersections with high proportions of large vehicles[15].

Through field research at the intersection of Jinzhai South Road and Zipeng Road in Hefei City, this study statistically analyzes traffic flow patterns and signal timing schemes at the intersection, evaluates its capacity capacity, and optimizes the signal timing configuration.

2 Evaluation Indicators for Intersections

2.1 Traffic Capacity

Throughput capacity refers to the maximum number of vehicles that can pass through a road or a specific road section per unit time when vehicles travel at acceptable speeds under existing traffic control and road conditions, denoted as Q.The current throughput capacity calculation for planar intersections employs the saturation flow rate model.The relationship between throughput capacity at each entrance and saturation flow rate as well as the green signal-to-talk ratio can be calculated using the following formula:

$$Q = S \cdot \lambda = S \cdot \frac{g_e}{C} \tag{1}$$

In the formula: Q — the capacity of the inlet(pcu/h); S— the saturation flow rate of the lane group (pcu/h); λ —the green signal ratio; g_e—the green light duration; C — the signal period.

2.2 Saturation

Saturation refers to the ratio of actual road traffic volume to capacity, denoted by x .

$$x = \frac{q}{Q} \tag{2}$$

In the formula: x —the saturation; q —the actual road traffic volume; Q—the capacity of the inlet(pcu/h).

2.3 Queue Length

As mentioned, the queue length is an important measure to evaluate the traffic optimization status of a planer signalised intersection. Common queue length related measures are time-period percentile queue length,average queue length and max queue length. Average queue length is defined as the mean vehicle length of intersection entrys during certain observed period (usually one or more signal cycle) ,providing an intuitive measure of congestion level and mean vehicular delay.The maximum queue corresponds to the maximum delay experienced by various lanes of an approach over the duration of a simulation,real-time information on traffic conditions in the streets.

2.4 Vehicle Delays

Vehicle delay refers to the total time consumed by drivers during driving due to traffic control facilities such as signal lights and slow-moving traffic,or other factors.From the perspective of the entire movement process of vehicles passing through intersections,the delay time for vehicle crossing an intersection consists of three components:deceleration delay time,stop delay time,and acceleration delay time.The VISSIM simulation software includes evaluation indicators such as vehicle delay,static parking delay,and per capita delay.As shown in Fig 1. This study adopts vehicle delay and static parking delay as the evaluation metrics.

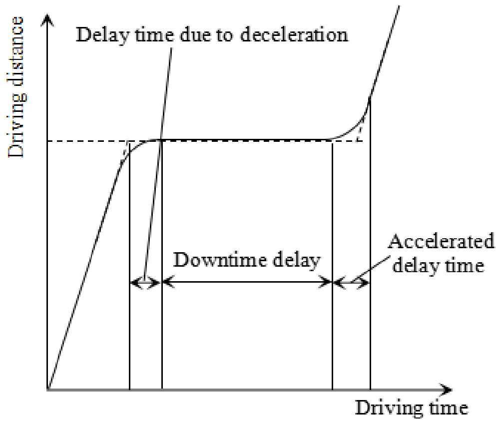

Fig. 1. Driving time-distance at intersections channelization

2.5 Number of Stops

The stop count is defined as how many times vehicles are stopped by traffic signals on a street intersection and reflects how much parking behaviors occur when they cannot move forward because of congestion. Actually,vehicles that are stopped due to the traffic lights at intersections do not totally halt, some vehicles will accelerate to regain its previous velocity and only then decelerate to a full halt.Thus according to the real traffic condition in intersection, the parking behavior of blocked vehicle is divided into two categories: full-stop and partial-stop.

3 Analysis of the Intersection of Jinzhai South Road and Zipeng Road in Hefei City

3.1 Investigation of the Current Situation of the Intersection

This study selects the intersection of Jinzhai South Road and Zipeng Road in Hefei City as the case study for traffic organization optimization design.Located in the Economic Development Zone of Feixi County,surrounding the main buildings: Feicui Garden,Jinxiu Dadi City,Feicui Lake,the surrounding area has a large number of pedestrians and vehicles in the morning and evening rush hour period.The intersection has four incoming lanes and four outgoing lanes, where every lane is provided with straightthrough,left-turn,and right-turn lanes.The northern entrance of Jinzhai South Road has five lanes:one left-turn lane, three straight-through lanes,one through lane (right turn),and six southbound departures.The northern entry has six lanes: one turning lane,left four through,one right turn lane, and five southbound exits.The east entrance to Zipeng Road consists of a total of one mixed lane (combined) and one east-offramp lane, while the west entrance has a total of two lanes: one mixed lane (straight through and right turn), and one separate left turn lane.with one westbound exit lane. In the rush hour period,most of the lanes have a large number of queued vehicles .The channelization plan for the Jinzhai South Road - Zipeng Road crossroad is shown as Figure 2.

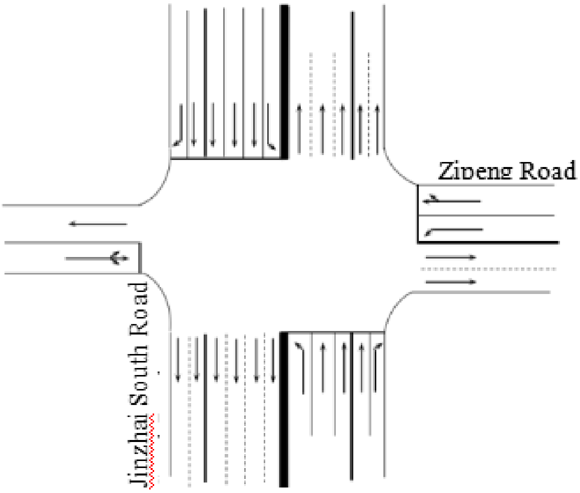

Fig. 2. Current status of intersection channelization

3.2 Investigation of Signal Timing at Crossroads

On-site observation of the intersection signal timing plan indicated that this intersection has a three-phase, fixed signal timing plan and its signal cycle length is 109 seconds. The phases do not change during the day:as shown in Fig. 3 and where the particular signal duration scheme can be found in Table 1.

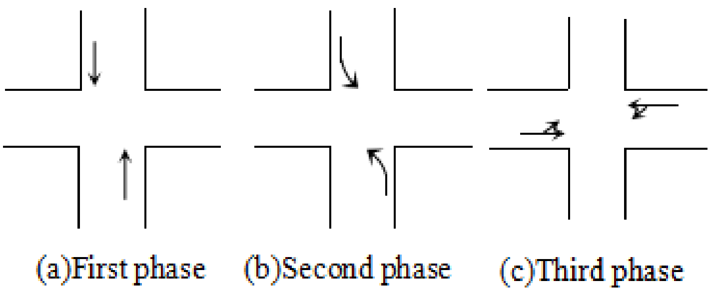

Fig. 3. Three phase diagram of traffic signal

Table 1. Investigation results of signal timing at the intersection of Jinzhai South Road and Zipeng Road

Schedule content	phase 1: left turn (North-South)	Phase 2: Straight Line(North-South)	phase 3: Straight and turn left(East-West)
Display green light duration	23	35	42
Yellow light time	3	3	3
Total time	26	38	45
Periodic time	109		

3.3 Traffic Flow Survey at the Intersection

Manual investigation method was used to conduct this traffic flow survey and the intersection has been surveyed in a morning peak time period of 7:30-8:30. The data were analysed and found that the traffic volume at straight ahead,left-turn, and right-turn lanes of the intersection (Table 2).

Table 2. Morning Peak Traffic Flow at the Intersection of Jinzhai South Road and Zipeng Road (pcu/h)

Import channel	Straight	Turn left	Turn right	Total
North import	1762	124	204	2090
South import	1980	400	56	2436
East import	80	116	116	312
West import	72	150	180	402

3.4 Calculation of Intersection Traffic Capacity and Saturation

The traffic capacity and saturation at the intersection of Jinzhai South Road and Zipeng Road can be calculated using formulas (1) and (2), as shown in Table 3.

Table 3. Traffic capacity and saturation of lane groups at the intersection of Jinzhai South Road and Zipeng Road

Import channel	Lane	q	Q	x
North import	Turn left	124	327.06	0.38
	Straight	1762	2119.27	0.83
	Turn right	204	497.71	0.41
South import	Turn left	400	327.06	1.22
	Straight	1980	2119.27	0.93
	Turn right+Turn right	56	497.71	0.11
East import	Straight+Turn right	116	597.25	0.19
	Turn left	196	635.78	0.31
West import	Turn left+ straight+turn right	402	616.51	0.65

From engineering practice, it is known that for an intersection to operate at best condition its degree of saturation should lie between 0.8 and 0.9. Based on this observation, we can sayboth the left turn lane and through lane at southbound approach to this intersection are above this saturation flow, indicating insufficient traffic capacity and persistent congestion. The primary cause lies in the north-south route serving as the main arterial connecting Feixi County with Hefei City's urban core.

4 Optimization Design of Intersection Organization

After researching and quantitative analysis, we find out that the traffic organization of this intersection can be improved from the aspect of signal timing so as to improve its capacity.

4.1 Signal Timing Optimization Design

Based on the traffic flow data analyzed, the calculated flow ratio at the intersection totals 0.81<0.9, allowing direct optimization of the signal timing scheme.According to the Webster timing scheme, the loss time formula for the intersection is as follows:

$$L = \sum_k (L_s + I - A)_k \tag{3}$$

In the formula: L is the total loss time of signal; L_s is the start loss time, which can be 3s; I is the green light interval time; A is the yellow light time, which can be 3s; k is the number of green light intervals in one period.

Signal period:

$$C_0 = \frac{1.5L + 5}{1 - Y} \tag{4}$$

In the formula: L is the total loss time of the signal and Y is the sum of the flow ratio.

The formula for effective green light time is:

$$G_e = C_0 - L \tag{5}$$

The effective green light duration for each phase is:

$$g_{ei} = G_e \frac{\max[y_i, yi_i' \cdots]}{Y} \tag{6}$$

The green light duration for each phase is:

$$g_i = g_{ei} - A_i + l_i \tag{7}$$

In the formula: A_i is the yellow light duration of phase i; l_i is the start-up loss time of phase i.

The optimized scheduling scheme based on formulas (3)-(7) is shown in Table 4.

Table 4. Optimized Signal Timing Scheme

Schedule content	phase 1: left turn (North-South)	Phase 2: Straight Line(North-South)	phase 3: Straight and turn left(East-West)
Display green light duration	29	35	30
Yellow light time	3	3	3
Total time	32	38	33
periodic time	103		

4.2 Simulation Analysis

Using VISSIM,we conducted simulation analysis on the optimized signal timing scheme to obtain intersection traffic efficiency data before and after optimization, as shown in Table 5.

Table 5. Comparison of evaluation indicators before and after intersection optimization

Project	Before optimiza-tion	After optimization	Beneficial result
Queue length	11.85	10.5	11.39%
Maximum queue length	118.62	105.58	10.99%
Average vehicle delay	31.77	26.89	15.36%
Static parking delay	24.31	19.82	18.47%
Parking count	0.79	0.72	8.86%

According to the comparison results between before and after optimization in terms of queue length, maximum queue length, average vehicle delay, static parking delay, parking frequency, it can be seen that the overall performance of signalized intersection has been greatly improved, which is reduced by 11.39% in queue length.maximum queue length, average vehicle delay, static parking delay, and parking frequency are reduced by 10.99%, 15.36%, 18.47%, and 8.86%, respectively (Table 5).The optimization result of service level evaluation index shows that the total efficiency in the intersection has been improved,suggesting considerable improvement results.

5 Conclusions

With the rapid development of cities, more people own vehicles which brings about serious traffic jams in the road junctions . The research object is the road junction between Jinzhai south street and zipeng street ,using field studies for assessing traffic status, by computing intersection capacity and degree of saturation,based on the application of optimal traffic control plans, and through simulation with the software VISSIM, as follows:

(1) Heavy traffic volume exists at the existing intersection, since the road in a northsouth direction is an important artery for connecting the Feixi urban area with Hefei urban area;The major delay occurs on the direction.

(2) The optimization result of the traffic signal time schedule is shown as Table 5 which shows that the queues are greatly improved,maximum queue length, average vehicle delay, static parking delay and parking frequency. Overall queue length at the intersection reduced by 11.39% ,maximum queue length (by 10.99%), average vehicle delay (by 15.36%), static parking delay (by 18.47%) and parking frequency (by 8.86%).The results showed that the capacities of intersections increased a lot after these measures and were optimized to some extent.

(3) The efficiency of city road intersections can be improved by reasonable traffic planning and design; optimizing signal timing is an important step in this process. The results of this paper provide a basis for subsequent optimization of traffic organization on the intersection.

Because we only have a few observations on traffic flows for the survey, our optimization solution here needs more empirical investigations.Because there will be evermore advanced technologies applied with intelligent transportations,the intersection can be upgraded as holographic intersection which can make traffic flow much more efficient and it is something we are going to implement in the future.

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