

Evaluation of X-shaped Intersection Reconstruction Scheme in Small and Medium-sized Cities

Jiaqi Zhang¹, Lin Zhang^{1,2,*}

¹College of Civil and Architectural Engineering, North China University of Science and Technology, Tangshan Hebei 063210, China

²Tangshan City Air and Ground Smart Transportation Key Laboratory, Tangshan Hebei 063210, China

Abstract: X-shaped intersections are deformed intersections, which are often blockages and difficulties in traffic governance in small and medium-sized cities. According to the actual needs of X-shaped intersection engineering transformation, the intersection widening design is combined with the left turn design of the borrowing road, and the traffic operation status before and after the transformation is studied by simulation comparison, which shows that the proposed method has a good practical engineering effect.

Keywords: Intersection modification, Vissim simulation, Turn left on the road.

1. Introduction

From 2011 to 2020, China's private car ownership increased from 73,267,900 to 242,851,700 units. Traffic congestion in large cities is common, and congestion in small and medium-sized cities also needs to be solved urgently. The main reason for urban traffic congestion is that the growth of the number of motor vehicles does not match the existing road situation, and the method of improving the pressure of traffic congestion in small and medium-sized cities has changed from relying only on widening urban roads to combining expanded roads with intelligent transportation.

In small and medium-sized cities, the urban road network is generally becoming denser, but due to the existing conditions around the built roads, the reconstruction of old roads is very difficult. The scope of demolition and modification on both sides of the current road is limited, and the renovation plan combines the existing intelligent transportation equipment with the existing intelligent transportation equipment on the basis of limited demolition and modification, re-planning the road sign marking, and improving the traffic capacity of intersections. A new type of traffic organization, turning left by road [1], has gradually become popular and has achieved good results. For the application of left turn on the borrowing road, Zhang Ye et al. [2] put forward a series of constraints on the length of the variable lane of the exit lane and the relevant parameters of signal light timing, but it is not enough to maximize the traffic benefits of the left turn of the borrowing road, and only consider the length of the lane and the timing of the signal. Chu Yanlong [3] explained the static channelization of left turns on borrowing roads, sign setting, traffic signal guidance rules, etc. Left turns are not available at all intersections, and the number of lanes and left-turn traffic needs must be considered [4,5].

With the opening of routes such as the Jingfu Line and the Tangfeng Expressway, the traffic between Fengrun District and the surrounding urban areas has become increasingly close. As the main road of Fengrun District, Cao Xueqin Avenue has a large traffic flow, and the Lin Yin road is a secondary urban arterial road, which is narrow overall. The intersection has poor traffic during the evening rush hour and

needs to be renovated.

2. Introduction to the Current Situation of Intersections

The Cao Xueqin-Lin Yin road intersection (shown in Figure 1) is located in Fengrun District, Tangshan City, Hebei Province, adjacent to Xingfu Road in the north and Guanghua Road in the south, which is an important hub intersection in and out of Fengrun District. The intersection is an X-shaped intersection with an angle of approximately 54°. Through the overall layout of the roads in Fengrun District, it can be seen that Cao Xueqin Road is a main road that crosses Fengrun District from east to west, so the traffic flow is very large. At present, the traffic capacity of Cao Xueqin Road is good, but the Lin Yin road is a secondary trunk road that runs north-south across Fengrun District, and the overall width of the road is narrow, which limits the traffic efficiency of the entire intersection, resulting in poor traffic capacity and slow driving at the intersection.

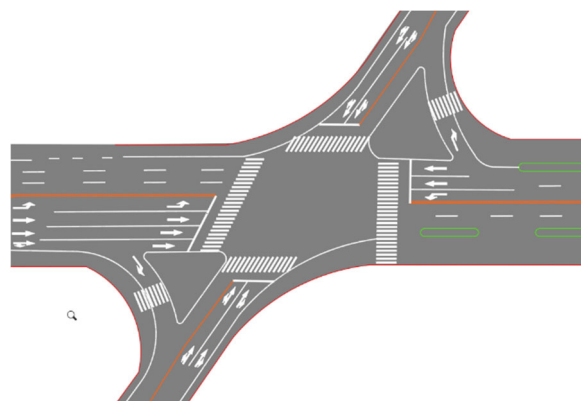


Figure 1. Schematic map of the current situation of Cao Xueqin-Lin Yin road

(1) Intersection lane distribution

Through actual research, the number of import and exit lanes at the Cao Xueqin-Lin Yin road intersection is shown in Table 1.

Table 1. Number of lanes in and out of the intersection

derection	Number of inlets	Number of exits	Distribution of inlet lanes
East	3	2	1 "Go straight + turn left" + 2 "Go straight"
South	2	1	1 "Go straight + turn left" + 1 "Go straight + turn right"
West	5	3	1 "Turn Left" + 3 "Go Straight" + 1 "Turn Right"
North	2	1	1 "Go straight + turn left" + 1 "Go straight + turn right"

It can be seen from the table 1 that the number of entry lanes at the intersection is greater than the number of exit lanes, which does not meet national standards, and is easy to cause accidents, making the intersection slow traffic.

(2) Intersection evening peak traffic statistics

The evening intersection video was taken by UAV, and then the evening peak traffic (hour) data was obtained, and the evening peak traffic data was shown in Table 2.

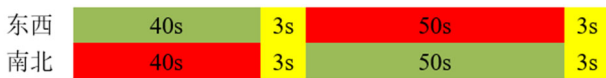
Table 2. Evening peak traffic data

Evening peak traffic data/train frequency		Turn left	Go straight	Turn right	Total
Cao Xueqin Avenue	East Exit	216	756	72	1044
	West Exit	144	336	240	720
Lin Yin Road	South Exit	264	648	72	984
	North Exit	12	540	228	780

By counting the peak traffic hour data, we can find that the traffic pressure at the east exit and the south exit is greater, there are more left-turning vehicles at the two entrances, and the total hourly traffic of peak traffic is about 30% more than that of the other two intersections

(3) Intersection status signal timing

Through actual research, the intersection uses one signal light for timing throughout the day. The intersection signal light has a total of two phases, and the current timing of the signal light is shown in Figure 2.

**Figure 2.** Current intersection signal light timing

(4) Investigation and simulation results of intersection status

Actual research queue length model, see Equation (1), Equation (2):

$$Q = (X - 1) \times S + \sum_1^i X_i \times L_i \quad (1)$$

$$X = \sum_1^i X_i \quad (2)$$

Q – queue length, m

X_i —Number of i th type vehicles, units

X - the total number of motor vehicles in line, units

L_i — the length of the i th type car, m

S – average interval between motor vehicles, m

where indicates the matching degree between the n th detected target and the m -track track; Due to the limitations of driver technology and night vision, the waiting interval between motor vehicles is measured between 0.8 meters ~ 2.5 meters, in order to facilitate research, $S=1.65m$.

Through aerial video and evening peak intersection research, we obtained that the average queue length of the east exit is about 84.75m, the average queue length of the south exit is about 132.7m, the average queue length of the west exit is about 28.2m, and the average queuing length of the north exit is about 37.4m.

Through the survey results, it can be found that the queue at the east exit and the south exit is long; Motor vehicles are often in the intersection conflict zone and travel slowly.

Then, using the obtained peak hour traffic data and the current traffic light of the intersection, VISSIM simulation software is used to simulate the current situation of the intersection (simulation time is 1 hour), and finally the simulation results are obtained (as shown in Table 3).

Table 3. Simulation results of intersection status

The name of the intersection	Import Road	Delay time(s)	Queue length(m)
Cao Xueqin-Lin Yin road	East Exit	25	72
	South Exit	11.9	240
	West Exit	22.2	72
	North Exit	18.8	228
Intersection average		21.9	---

3. Analysis of the Problems and Causes of The Implementation

Through the current situation investigation and combined with the current situation simulation results, we can find that there are the following problems in the current situation intersection:

(1) Lin Yin road: There are problems with traffic at the south exit during peak hours, and the car queue is long.

(2) Cao Xueqin Avenue: Evening rush, long queue time at the east entrance, slow driving.

(3) The timing of intersection signal lights is unreasonable, and the queue time of motor vehicles is long; There are many conflict areas at intersections, and motor vehicles travel slowly.

(4) The current situation of the intersection adopts the marking channelized island, and pedestrians and non-motor vehicles wait in the channelized island, but due to the chaotic traffic order of the intersection, it is difficult to ensure driving safety. Based on on-site observations, the number of pedestrians and non-motor vehicles at this intersection is not very large, and the existing canalized island area is large,

resulting in waste of resources.

(5) The sidewalk planning is unreasonable, and pedestrians do not take zebra crossings when crossing the road.

3.1. Analysis of the cause of intersection problems

Through actual research, the causes of the problems at the intersection are analyzed:

(1) The problem of non-mixed traffic in the south exit machine is prominent: the Lin Yin road road is narrow, and the width of the non-motor vehicle road on both sides is about 1.2~1.5 meters, which does not meet the current national standards. Non-motor vehicles often occupy motor lanes when driving, reducing the actual traffic capacity of the lanes.

(2) The current signal light is unreasonable in timing: the north and south entrance lanes of the intersection are both "straight left + straight right" two lanes, and the signal is released at the same time as the north-south straight traffic plus the left turn, and the conflict zone is obvious, resulting in a low overall traffic capacity of the morning and evening peak of the intersection. Traffic spikes during peak hours, but the timing of intersection signals is fixed, reducing the efficiency of intersections.

(3) The Lin Yin road is set up as 2 lanes of the entrance road and 1 lane of the exit road at the intersection. The number of inlets and exits does not match.

(4) The left turn at the east exit of Cao Xueqin Road is set in parallel with the straight road, resulting in chaotic order at the intersection.

(5) The area of channelized islands is unreasonable: the current situation of the intersection of the marking channelized island can be seen from the aerial map that the area is large, and it can be found that the utilization rate of channelized islands is not high by observing the morning and evening peaks.

4. Realize Design Difficulties and Scheme Design Ideas

4.1. Design difficulties

There are many difficulties in the reconstruction of intersections in small and medium-sized cities, and not all difficulties can be overcome due to the restrictions of the surrounding facilities, through the actual investigation around the intersection. The main findings are that there are three difficulties in the design:

(1) There are commercial, residential, park, hospital and other building facilities around the intersection, and the scope of road demolition and modification is limited.

(2) The intersection is located at the transportation hub in and out of Fengrun District, with a large traffic flow, a dense road network around it, and a close distance between intersections.

(3) There is a high-voltage line on the west side of the north entrance of the intersection, and relocation and reconstruction are prohibited.

4.2. Design target functionality

After connecting with relevant departments and conducting on-site investigation of construction conditions at intersections, the following functions are mainly realized:

(1) Primary-secondary connection: that is, the connection between Cao Xueqin Avenue and the Lin Yin road.

(2) Main-auxiliary connection: the connection between

Cao Xueqin Avenue and the auxiliary road connected to it.

(3) Sub-auxiliary connection: the connection of the Lin Yin road and the auxiliary road connected to it.

(4) The intersection is located in the town, and the slow traffic system and public transport system must be considered, and the convenience of residents' travel is an important part of evaluating whether the road design is qualified.

Under the premise of complying with national norms, the road design to ensure the above functions should also improve the efficiency of motor vehicle traffic at intersections.

5. Introduction of the Renovation Design Scheme

Through the research and analysis of demand analysis and actual intersection situation, combined with the characteristics of evening peak traffic data, Caoxueqin Avenue-Boulevard adopts the "marking mode" and the traffic organization mode of turning left on the borrowing road to carry out the intersection transformation according to local conditions. The effect of the transformation scheme is shown in Figure 3:

The entire intersection was re-milled with covers, marked lines were applied, and signal timing was changed.

(1) The lane on the east side of the intersection is widened, and one lane is added to the entrance road and one lane for the exit road; Increase the left turn lane of the borrowing road, reduce the queue length of the left turn into the Lin Yin road on Cao Xueqin Avenue, and improve the traffic efficiency.

(2) The south entrance was expanded, and the non-mixed traffic mode of the original machine was changed to non-common board traffic; The south exit entrance lane is separated from the left turn lane, and the exit lane is increased by two.

(3) The stop line at the entrance road on the west side of the intersection is moved back and the marking line is re-applied.

(4) The north side of the intersection separates motor vehicles and non-motor vehicles, changes the original non-mixed traffic mode to non-common board traffic, separates the left turn lane on the north side of the intersection, and adds one lane each for the entrance road and the exit road.

(5) The signal timing is changed from the original two phases to the four phases after the scheme (due to the increase of the left turn of the borrowing channel, the phase of the intersection is put left first).

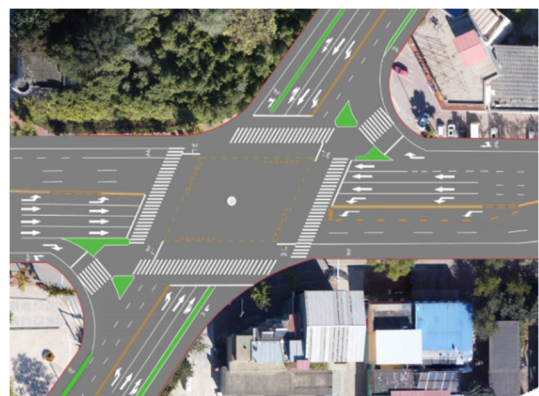


Figure 3. Renderings of the renovation plan

According to the survey data, it can be learned that the number of left-turning vehicles at the South Exit is not much different from the number of left-turning vehicles at the East Exit, but the East Exit adopts the borrowing road left-turn

traffic organization method, while the South Exit does not adopt the borrowing road left-turn traffic organization method for the following two reasons:

(1) Due to the angle of the entire intersection, the gradient section of the south exit is only 27.5 meters, and the short left turn lane of the borrowing road has little impact on improving the efficiency of the intersection.

(2) Due to the angle problem of the entire intersection. There are two left-turn lanes at the south exit that are prone to collisions.

In summary, the south exit of the plan does not set up a borrowing road to turn left, and the traffic capacity of the left

turn at the south exit is improved by adjusting the timing of the signal light in the later stage.

Simulation comparison and analysis results before and after transformation:

In this paper, the data is collected according to the current situation and the traffic light of the intersection, and the VISSIM simulation software is used to simulate the current situation of the intersection (simulation time is 1 hour), and finally the simulation results of the scheme are obtained, and then the effect before and after the transformation is compared (as shown in Table 4).

Table 4. Before and after the transformation

Import Road	Delay time(s)			Queue length(m)		
	Before	After	Changing trends	Before	After	Changing trends
East Exit	25	14.3	↓	15	25	↑
South Exit	11.9	12.1	↑	119	21	↓
West Exit	22.2	15.9	↓	6	15	↑
North Exit	18.8	17.9	↓	13	23	↑
Intersection	21.9	14.8	↓	---	---	---

(Note: The left turn part of the borrowing road simulated by the transformation plan is simulated by establishing a virtual road and reasonably setting the position of the signal light.)

Through the comparison results before and after the renovation, we can know that the average delay of the renovated intersection has been greatly improved, and the transformation effect is obvious. However, the queue length is only reduced at the south exit, and the analysis is that the timing phase of the intersection signal is increased and the signal period is longer. Although the queuing length is only reduced by the south exit, the queuing length of the renovation plan is between 15-25m, indicating that the intersection meets the requirements of urban intersection traffic in a smooth peer state. The simulation results of intersection conditions before and after the renovation illustrate the feasibility and superiority of left turn by road, and provide reference significance for the intersection reconstruction of other small and medium-sized cities.

6. Conclusion

By analyzing the primary and secondary contradictions of traffic demand, combined with peak traffic flow data and actual intersection road conditions, this paper improves the traffic capacity of intersections in the traditional intersection reconstruction design and the organizational form of left-turn traffic on the borrowed road. The simulation results of VISSIM software show the feasibility of turning left on the borrowing lane to improve the efficiency of intersections. However, the simulation model of the renovated intersection needs to be further improved.

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