Optimization of Safety Facilities for Collision Analysis between Motor and Non-Motor Vehicles at Intersections

Na Zhao*, Jihui Ma[a]

School of Traffic and Transportation, Beijing Jiao tong University

ABSTRACT: With the increasing number of the motor and non-motor vehicles, conflicts and safety risks between motor vehicles and non-motor vehicles are increasing. Among them, the collision between right-turning vehicles and non-motor vehicles going straight leads to traffic accidents accounting for up to 50% of the non-accident cases at intersections. The intersection of Erdos East Street and Xing an' South Road in Hohhot City is selected as the research object. Analyze the conflict between right-turning motor vehicles and non-motor vehicles. The optimized design was carried out from three perspectives: right-turn channelization island design, road deceleration facilities layout, and signal control, and the road network model was built with VISSIM survey data to demonstrate and evaluate the scheme. The results show that when the traffic volume is unchanged, the number of non-collision decreases and the passage time of non-motor vehicles decreases by 4%. The travel time for left-turn vehicles also dropped 16 percent. It shows that the collision between motor vehicles and non-motor vehicles at right-turn intersections is significantly improved through the above optimal design scheme.

1. INTRODUCTION

As of 2022, with the development of our society, the number of motor vehicles has increased. The share of non-motorized vehicles as the main mode of travel for residents is increasing, and we need to see the traffic problems that arise while enjoying the convenience brought by development.

Through consulting relevant data, it is found that the collision between right-turning vehicles at the intersection and non-motor vehicles running straight across the street leads to traffic accidents accounting for up to 50% in a series of non-accident cases. However, traffic conflicts caused by small turning radius of turning vehicles, blindsight area of large vehicles when turning right, lane occupation between non-motor vehicles and motor vehicles, often lead to traffic delays and accidents of different degrees. For specific intersections of the machine non-conflict to achieve specific problem-specific analysis, this paper puts forward a targeted safety facilities optimization design scheme, which can be more efficient to optimize the design of the intersection, so that the design truly benefits the traffic participants, while guaranteeing the safety of non-motor vehicles across the street, improve the efficiency of motor vehicles, promote the design from "car standard" to "human standard" transformation.

So far, the current status of domestic and international research is mainly on the study of traffic conflicts at urban signal intersections, mainly in analyzing the characteristics of machine-non-conflict participants, establishing the evaluation system of the severity of machine-non-conflict at intersections, and designing conflict mitigation schemes. Yang et al. (2020) obtained that the expansion degree of non-motor vehicles would first increase and then decrease with green time [9]. Zeng (2018) concluded that the conversion coefficient of electric bicycles under conflict conditions was 1.290 [11]. Jing (2005) aiming at the characteristics of conflicts, optimized the design of the intersection to make the traffic flow more orderly in time and space, reduce interference, and thus reduce traffic conflicts [5]. Yu (2018) analyzed that the conflict between motor vehicles and non-motor vehicles is mainly affected by vehicle state, road environment, and rider characteristics[10]. Han (2019) established a grey cluster evaluation model for evaluating the safety of traffic conflicts at intersections with conflict rate and proportion of serious conflicts as evaluation indexes[4]. Cheng et al. (2019) constructed a relationship model between the amount of bicycle traffic on the side of a single lane and the number of non-collision cycles to provide a reference for the design of bicycle lane width[2]. Peng (2017) according to the application effects of shaped and colored zebra crossings, presented that optical illusion zebra crossings play a positive role in vehicle deceleration[6]. Ge (2020) took bicycles as a research object to analyze the impact of the lane-changing process of vehicles entering the station on the operation of non-motor vehicles [3]. Buch et al. (2017) analyzed the interference of motor vehicles with non-motor vehicles by establishing a safety assessment index and showed that the stop line could not reduce the conflict between right-turning motor vehicles and bicycles [1]. Stipancic (2016)

*21120774@bjtu.edu.cn, [a]jhma@bjtu.edu.cn

determined the vehicle's right-turn track and blind spot model through the dynamic simulation of the vehicle's right-turn process [7]. Van (2017) demonstrates the necessity of segregation between motor vehicles and non-motor vehicles [8].

Through the review of literature, studies on traffic safety design mostly focus on a single facility. It is found that studies on the conflict between right-turning vehicles and non-vehicles going straight at intersections focus on the analysis of non-collision, but there are fewer studies on the mitigation strategies of non-collision at intersections. Domestic and foreign scholars have proposed a series of countermeasures to alleviate the conflicts between right-turning vehicles and non-motor vehicles, which account for the largest proportion of non-non-motor vehicle conflicts at intersections. However, there is still a lack of detailed research on the specific use methods and applicability of different intersections.

Because of the external research on the non-conflict of the right-turning machine, this paper will take a school district intersection with serious non-conflict as the research object, according to the actual situation of the intersection, establish the relationship model between the number of parking times of each import right-turning vehicle and the number of non-motor vehicles on the side of the road, and provide the optimization design method of safety facilities according to local conditions for prominent problems, so as to alleviate the non-conflict of the right-turning machine. The purpose of improving intersection safety.

2. CHARACTERISTCS OF COLLISION BETWEEN MOTOR VEHICLES AND NON-MOTOR VEHICLES AT INTERSECTIONS

2.1. Definition of conflict between motor and non-motor vehicles

At urban road intersections, motor vehicles and non-motor vehicles approach each other at the same time, and both parties perceive the existence of dangerous traffic. In order to avoid traffic accidents, one party changes the speed and direction of traffic behavior.

2.2. Analysis of conflict process between motor vehicles and non-motor vehicles

Machine non-conflict means that when motor vehicles and non-motor vehicles are facing a collision accident in the conflict zone, they control the vehicle through the perception of traffic information and subjective judgment to change the speed and direction of the vehicle. If the control succeeds in adjusting the vehicle state, the accident will be avoided; if the collision fails, the collision will occur.

2.3. Characteristics of between motor vehicles and non-motor vehicles

According to the definition, one typical intersection in Hohhot city (Ordos East Street - Xing'an South Road), shown in Table 1, is selected to collect the machine-non-motorized conflict data during the peak period of 18:00-19:00 when students are out of school to analyze the right-turn machine-non-motorized conflict at urban road intersections. As shown in Figure 1, this intersection is a five-phase intersection.

From the perspective of non-motorized vehicles traveling from north to south, there are conflicts between phase 1 straight non-motorized vehicles and north import right-turn vehicles, west import left-turn and right-turn vehicles, and conflicts between phase 4 and phase 5 straight non-motorized vehicles and north import right-turn, and they fall into the intertwined area of west import right-turn and north import straight-turn vehicles in the west import and south exit area. Therefore, the data on the number of right-turning motor vehicles and roadside non-motorized vehicles are mainly collected to analyze the machine-non-conflict characteristics. The right-turn machine-non-conflict mainly includes the conflicting speed, distance, position, and angle of machine-non-conflict.

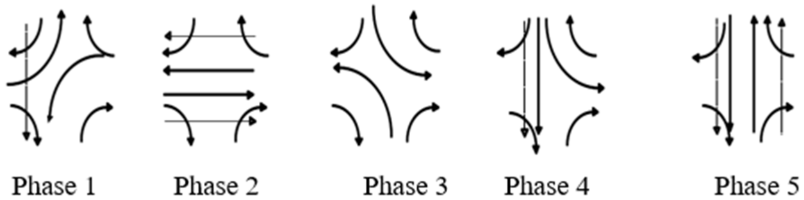

Figure 1. Intersection phase conflict diagram

Table 1. Cross-sectional arrangement of roads

Roads	Road grade	Motor vehicle road width /m	Separation of motorized and non-motorized vehicles	Non-motorized road width /m
Ordos East Street (East side)	secondary road	3.5*4+3.5	None	3.0
Ordos East Street (West side)	secondary road	3.5*3+3.5	None	3.0
Xing'an South Road (South side)	secondary road	3.5*4+3.5	None	3.5
Xing'an South Road (North side)	secondary road	3.5*3+3.5	Have（2.5m）	3.5

3. EMPIRICAL RESEARCH

3.1. Conflict Modeling

According to the current characteristics that motor vehicles occupy a mainstream position in right-of-way allocation and the number of non-motor vehicles increases rapidly, referring to Cheng Guozhu et al[2] in the non-conflict analysis of urban road machines and the calculation method of bicycle lane width, regression analysis is used to build and simulate the correlation between the number of bicycles at different entrance roads and the number of right-turn motor vehicles stopping. The function with the highest degree of fit was found as the related function of the inlet lane, and the calculating model of the non-conflict number of the right transfer at a certain moment of the intersection was constructed by summing the relation of each inlet lane function. The regression analysis curve was used to fit the scatter diagram, and the function with the highest degree of fit was taken as the non-conflict relation of each inlet right-turning machine.

In the fitting of the relationship between the number of bicycles at each inlet side of the road and the non-conflict number of the machine, it is found that the quadratic function has a higher degree of fitting, so the quadratic function is expressed as:

$$y_1 = 0.0298x_1^2 - 0.4189x_1 + 2.3556 \tag{1}$$

$$y_2 = 0.0085x_2^2 - 0.0430x_2 + 0.4320 \tag{2}$$

$$y_3 = 0.0101x_3^2 - 0.1430x_3 - 1.6703 \tag{3}$$

$$y_4 = 0.0291x_4^2 + 0.0138x_4 + 0.2872 \tag{4}$$

Where y_i-the number of conflicts at each inlet; x_i- the number of non-motorized vehicles at each inlet.

Accumulate equations (1), (2), (3), and (4) to establish the intersection machine non-conflict calculation model.

$$Y = y_1 + y_2 + y_3 + y_4 \tag{5}$$

Counting the number of roadside non-motorized bicycles in each inlet lane at a certain moment, combined with the fitted relationship equation for each inlet, the calculation of the number of right-turn machine-non-conflicts at this intersection can be achieved using equation (5). Observing the number of roadside bicycles and the number of conflicts at each inlet, it can be seen that the number of right-turning motor vehicle stops increases with the number of roadside non-motorized vehicles. The function fit reveals a quadratic relationship between right-turning motor vehicles and roadside non-motorized vehicles at each inlet, as shown in Figure 2.

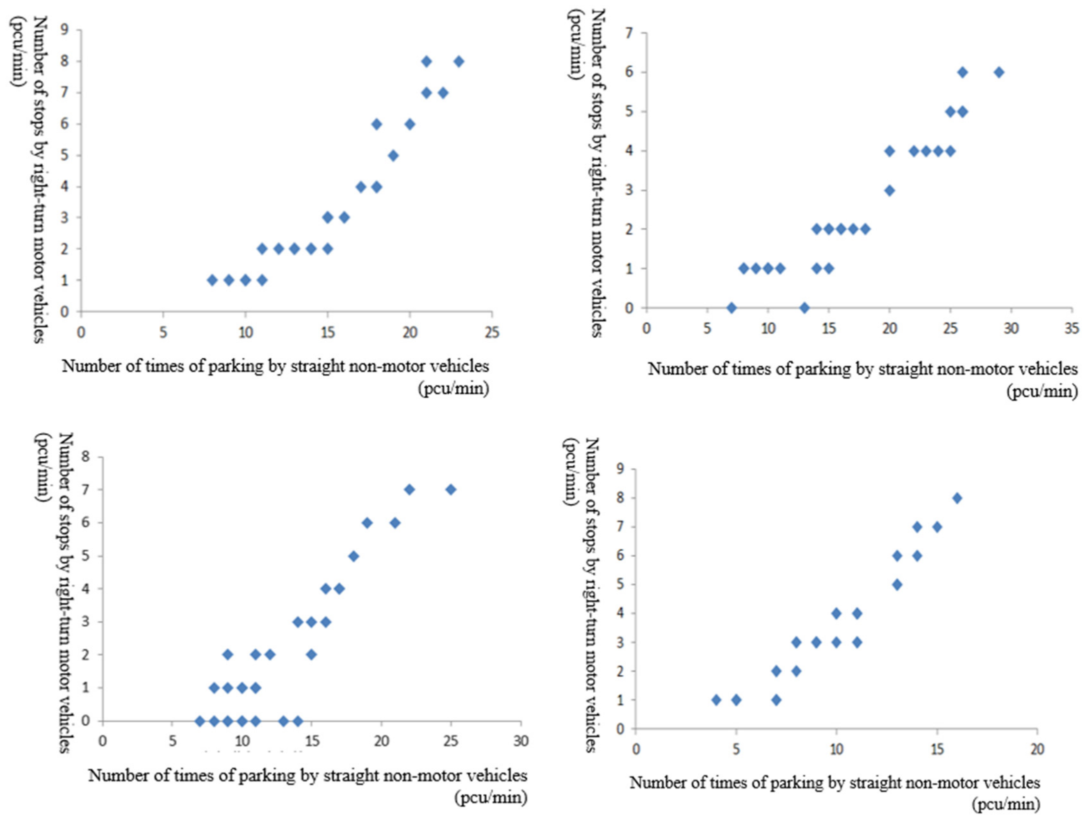

Figure 2. Number of non-motor vehicles and stopping times of right-turning motor vehicles at the west, east, south, and north entrance roads

If you want to reduce the non-conflict at the intersection, it is still necessary to start with the motor vehicles with greater right of way, which are more easily controlled by rules, to control the motor vehicle flow in time and space, and reduce its conflict points with the non-motor vehicle flow.

3.2. Optimal design of safety facilities for a right turn at the intersection

Through the observation of the non-conflict situation of right-turning machines at each intersection, it is found that the main reasons for the non-conflict of right-turning machines at each intersection are as follows: The south entrance is an urban expressway with no large personnel distribution center such as schools, and the traffic volume in this period is not dense, so right-turning vehicles turn too fast at the intersection. The West African motor vehicle entrance road has accumulated, and even enters the turning path of right-turning motor vehicles, which enlarges the turning radius of turning vehicles, thus hindering the vehicles going straight to the north entrance. The south entrance road makes the confluence space of right-turning motor vehicles and straight-going motor vehicles at the north entrance squeezed, causing obstacles to the passage, and the number of right-turning motor vehicles stopping reaches the peak. To alleviate machine non-conflict, the following optimization suggestions are put forward:

3.2.1. Design of road deceleration facilities

When the vehicle runs at a higher speed, the driver's line of sight will also increase and narrow the speed of the accompanying vehicle, thus prolonging his response time to emergencies and increasing the risk of accidents. At present, drivers are visually reminded to slow down by changing the paving of road junctions or marking road lines with eye-catching colors. The problem of the fast turning speed of right-turning motor vehicles at the south entrance can be considered from the above Angle.

1) Setting of vibration marking

Right-turning vehicles at the south entrance may leave the viaduct and drive smoothly on the smooth section at a higher speed to reach the intersection. With reference to the marking specifications, an optimized design scheme of continuous 450cm yellow deceleration vibration marking is proposed in Figure 3 in front of the entrance of the right-turning lane according to the lane width of 350cm. When the vehicle passes the deceleration vibration marking at a faster speed, the driver hears the roar and produces a sense of jolting, which can make the driver reduce the speed before passing the deceleration vibration marking, and the speed when turning right will also decrease accordingly.

2) Colored marble pavement at the intersection

In the design, combined with the conclusions of Peng Zeqian et al., the design method of laying the marble pavement in Figure 4 with red masonry in the intersection was proposed.

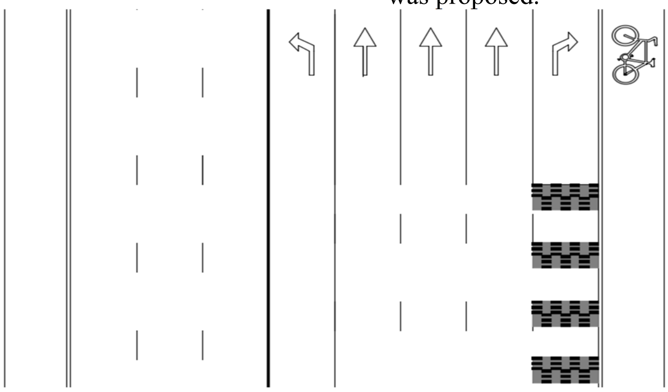

Figure 3. Location of vibration markers

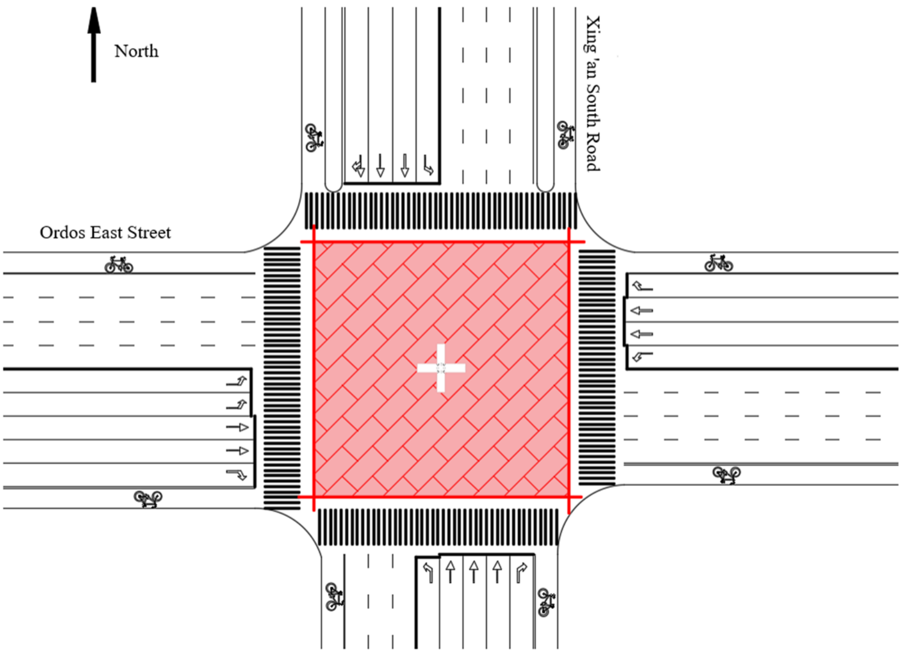

Figure 4. Colored pavement inside the intersection

3.2.2. Optimization design of signal control

1) Release non-motor vehicles in advance

A large number of non-motorized vehicles at the north import overflow the waiting area while waiting for passage, and the queue width extends to the front of the motor vehicle parking line, which not only makes it difficult for right-turning vehicles to turn and impede the passage of straight ahead vehicles but also generates scraping with straight-ahead vehicles. Because the north import motor vehicles than non-motorized vehicles released in advance, to avoid the accumulation of non-motorized vehicles should be optimized from the signal timing design, to achieve early release of non-motorized vehicles. In the third phase of the motor vehicle, the yellow light began at the same time to release the north import straight non-motorized vehicles, because the 3s yellow light time is not enough for non-motorized vehicles to affect the north-south left-turning motor vehicles to clear the tail, the non-motorized vehicle phase 3 of the green light time forward to extend 10s to achieve early release, which will help reduce the accumulation of non-motorized vehicles.

2) Right-turn signal control and phase sequence recombination

According to the phase timing of the investigation cycle, it is found that the machine running straight at the north entrance has most of the green time in the cycle time, which is consistent with the situation of students when they leave school. The design of 5 entrance lanes and 3 exit lanes on the south side of the intersection cannot provide enough confluence space for right-turning motor vehicles and northbound direct motor vehicles and non-motor vehicles, resulting in serious non-collision in the interweaving area.

To ensure the safety of non-motor vehicles traffic and reduce the frequency of conflicts in the intertwined area, signal control, and phase sequence reorganization are carried out for right-turning motor vehicles at the west import. The optimization plan is proposed: as shown in Figure 5, a right-turn arrow light that can only light red and yellow is added at the west import, and non-motor vehicles are prohibited at phase 1. phases 2 and 3 remain unchanged; phases 4 and 5 are prohibited for right-turn motorized traffic at the west import, and phase 5 is adjusted before phase 3 based on the prohibited design.

3) Right-turn isolation facility design

The radius of turning right at the east entrance of the intersection is large, and the parking position of non-motor vehicles and pedestrians is too far ahead when waiting for the red light. When large vehicles turn right, non-motor vehicles or pedestrians in the "mirror blind area" cannot be seen. When a car runs into obstacles, it can increase the turning Angle in a short time to change the driving track to avoid non-motor vehicles. If the turning of large vehicles and non-motor vehicles are too close, under the action of the inner wheel difference, the rear wheel approaching non-motor vehicles may cause rolling accidents. Through consulting the data, it is found that all the isolation facilities set have constraints on the driving track of traffic participants at the intersection to reduce the non-conflict. When designing isolation facilities, the inner wheel difference of large vehicles was selected as the design basis, and the right-turn isolation facilities were designed at the northeast corner.

3.3. Simulation evaluation of optimized design scheme

3.3.1. Layout of safety facilities at the intersection

In order to ensure the safety of non-motor vehicles crossing the street, for the problem of the fast speed of right-turning vehicles at the south entrance of the intersection and large turning radius at the north entrance, from the idea of speed control and direction control, the plan of additional safety facilities is proposed. Figure 6 shows the effect of safety facilities after laying the bullet stone pavement, laying the speed reduction vibration markings, and installing additional right-turn machine non-separation facilities inside the intersection, in front of the right-turn lane of the south import and near the right-turn lane of the east entrance respectively.

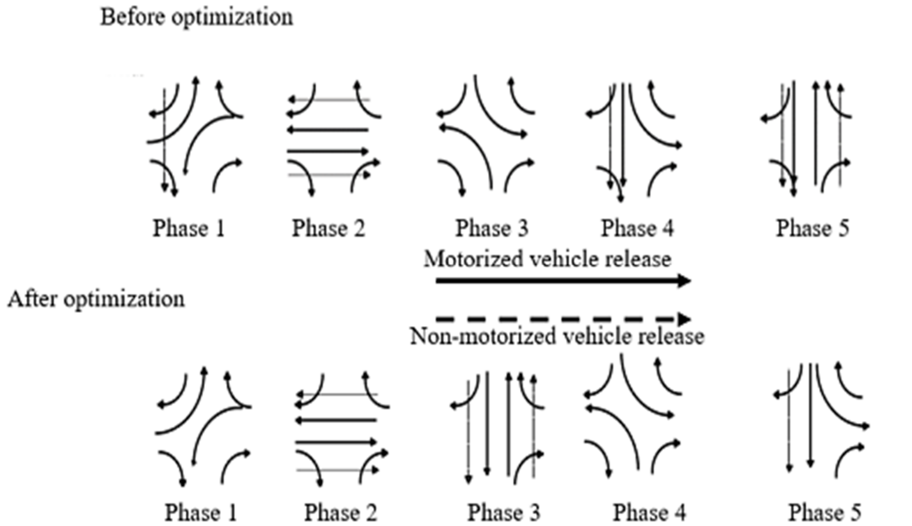

Figure 5. Optimization of motor vehicle and non-motor vehicle release scheme at intersections

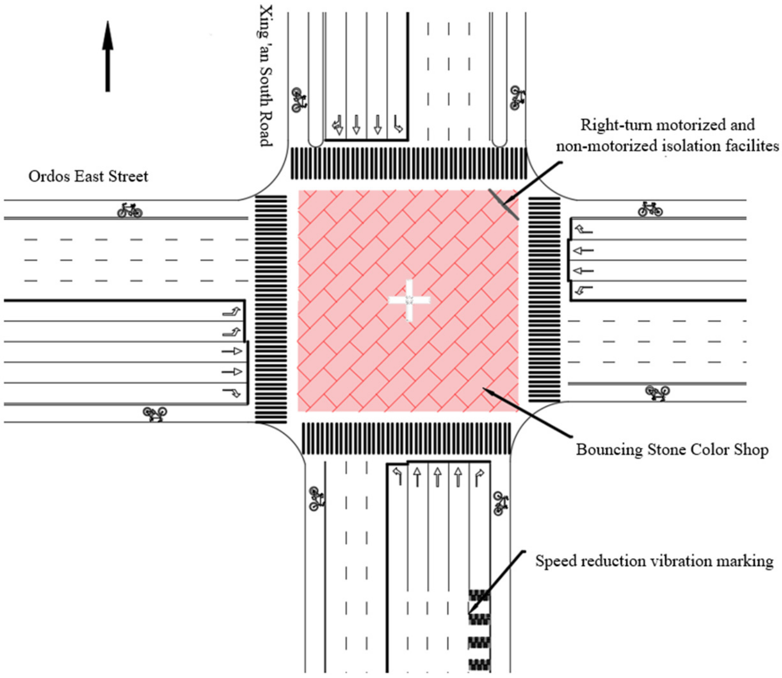

Figure 6. Intersection Safety Facilities Layout

3.3.2. Right-hand turn signal control effect

Given the interference caused by the accumulation of non-motor vehicles in the north of the crossing on the same side of straight and right turn vehicles and the conflict in the complex confluence of non-motor vehicles and non-motor vehicles in the west, the design schemes of early release non-motor vehicles and right turn signal control were proposed respectively from the point of view of signal control. According to the superposition results of the two optimization design timing schemes mentioned above, the traffic simulation modeling tool VISSIM was used to simulate the running conditions of vehicles before and after the design to demonstrate the feasibility of the scheme.

1) Traffic simulation modeling

The intersection diagram was imported into VISSIM in CAD format, the lane and connector were drawn and combined with the survey data, the traffic volume was divided for each lane, the driving path was determined, and the signal cycle was edited in the signal control machine according to the timing plan table. Finally, signal lamps are set in each inlet lane according to the timing scheme, completing the preliminary construction of the road network model. Data collection points are set in each lane at the entrance of the west and north to delimit the travel time detection interval on the vehicle crossing path, and form data acquisition facilities and travel time detection sections according to the driving direction, to prepare for the queuing delay and travel time of vehicles in all directions before and after optimization. Finally, run the simulation model, collect the simulation result data, and compare the results to verify the optimization design effect.

2) Comparative analysis of traffic simulation results

The simulation results of the travel time before and after the optimization of vehicles in each direction at the westbound entrance are shown in Table 2. By comparing the travel time of vehicles in all directions at the west entrance before and after optimization, it is found that the travel time of right-turning vehicles increases by 8s after setting the right turn signal light. Because the signal control does not involve the passing of vehicles going straight, the travel time of vehicles going straight is not affected. After controlling the turn of right-turning motor vehicle, the number of non-conflict between non-motor vehicles and non-motor vehicles in straight running decreased, and the passage time of non-motor vehicles decreased by 4%; The passage of left-turning vehicles was smooth due to the reduced release phase of non-motor vehicles going straight at the north entrance, and the travel time of left-turning vehicles also decreased by 16%.

Table 2. Comparison of travel time simulation results

Import	Vehicle direction	Status quo travel time(s)	Optimized travel time(s)
West import	Go straight on non-motor vehicles	77	74
	Right-turn motor vehicle	14	16
	Left-turn motor vehicle	37	31
	Straight motor vehicle	29	29

The simulation results of queuing delay before and after the optimization of vehicles in all directions at the north entrance are shown in Table 3. Since the optimization does not involve left-turning vehicles, the queuing delay is almost unchanged. Although the queuing delay of non-motor vehicles increased by 4s due to the decrease of the green time at the north entrance, from the perspective of the queuing delay of north-imported vehicles, the queuing delay of straight-going vehicles decreased from 24s to 11s due to the conflict point with right-turning vehicles and the decrease of non-motor vehicles accumulation at the side of the road. When the release of straight-going vehicles becomes smooth, the interference of right-turning vehicles in the straight-right lane is reduced, and the queuing delay is reduced by 62%.

Table 3. Comparison of queuing delay simulation results

Import	Vehicle direction	Current queuing delay(s)	Optimized queuing delay(s)
North Import	Go straight on non-motor vehicles	10	14
	Right-turn motor vehicle	13	5
	Left-turn motor vehicle	40	38
	Straight motor vehicle	24	11

Based on the above analysis, it can be seen that the optimized design scheme of allowing non-motor vehicles running straight at the north entrance to release when the yellow light of left-turning motor vehicles in the north and south turns on, and phase sequence regulation on the basis of adding signal control to right-turning motor vehicles in the west entrance, reduces the queuing delay of vehicles in the north entrance, reduces the travel time of vehicles in the west entrance, and alleviates the non-conflict of the right-turning machine. The feasibility of the optimization scheme is proved from the side.

4. CONCLUSION

The road network can not only allow all kinds of vehicles to pass, but also provide special space for buses, bicycles, and pedestrians on the streets. However, most of the road space is specially designed for cars. Uneven distribution of the right of way often leads to conflicts between motor vehicles and non-motor vehicles, increasing the probability of accidents. The optimized design of safety facilities at intersections can reduce conflicts and improve traffic efficiency and safety. Based on the analysis of the non-conflict of right-turning machines at urban road intersections, the optimal design scheme of safety facilities is put forward to alleviate the non-conflict of right-turning machines. Specific conclusions are as follows:

1)The non-conflict of the right-turning machine will increase with the increase of non-motor vehicles on the side of the road. Establishing a relationship model for the number of non-stopping times of the right-turning machine can realize the number of right-turning conflicts at intersections.

2)Add a right turn signal light at the entrance with serious non-collision, adjust the phase sequence at the same time, reduce the number of non-collision between non-motor vehicles running straight and non-motor vehicles, and reduce the passage time of non-motor vehicles by 4%; The passage of left-turning vehicles was smooth due to the reduced release phase of non-motor vehicles going straight at the north entrance, and the travel time of left-turning vehicles also decreased by 16%.

3) If permitted some deceleration facilities should be added to control the turning path and speed of right-turning vehicles, which can give non-aircraft drivers more escape space and reaction time, and also help reduce the severity of non-aircraft collision accidents.

The above conclusions can prove that the research content of this paper has practical guidance significance, whether it is to set up a slowdown road or separation facilities to restrict the path of right-turning vehicles or to release non-motorized vehicles in advance and signal control for right-turning vehicles, which can help reduce the accumulation of non-motor vehicles on the roadside and alleviate the right-turning machine-office conflict problem.

REFERENCES

1. Buch, T. S, & Jensen, S. U. (2016). Incidents between straight-ahead cyclists and right-turning motor vehicles at signalised junctions. Accid Anal Prev, 105(aug.), 44-51.
2. Cheng, G.Z & Wang, W. Q. (2019). Analysis of Machine-Non-Conflict and Calculation Method of Bicycle Lane Width on Urban Roads. Journal of Harbin Institute of Technology,51(09):130-136.
3. Ge, L.Jn. (2020). Research on the optimization of continuous passage space of non-motorized lanes based on machine-non-conflict analysis". Central South University of Forestry Science and Technology.
4. Han, L. (2019). Signal intersection machine and non-traffic conflict discrimination and safety evaluation model. Changsha University of Technology.
5. Jing, C. G. (2005). Study on the non-conflict mechanism of planar intersection machine and its application [D]. Jilin: Jilin University, 2005.
6. Peng, Z. Q. (2017). Research on the application of shaped and colored crosswalks at urban road level crossings. Highway and steam transportation, (06):49-52.
7. Stipancic J,et a1.(2016). Investigating the gender differences on bicycle-vehicle conflicts at urban intersections using an ordered logit methodology. Accident Analysis & Prevention ,97:19-27.
8. Van, D, Goede, M. D, Hair-Buijssen, S. D, & Methorst, R. (2014). Traffic conflicts on bicycle paths: a systematic observation of behaviour from video. Accident Analysis & Prevention, 62, 358-368.
9. Yang, X.F & Fang, D. M. (2020). Study on the Conflict Behavior Between Vehicles and Bicycles Considering Driving Psychology. Journal of East China Jiaotong University.
10. Yu,R. K. (2018). Analysis of Conflict Behavior between Motor Vehicle and non-motor vehicle at Right Turn at signalized Intersection [D]. Beijing: Beijing Jiaotong University.
11. Zeng, M. (2018). Conflict-based research on the safety of traffic flow in independent urban non-motorized lanes. Chang'an University