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Review on the Development of Left Turn Crossing Theory of Non-Motor Vehicles

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Abstract: Non-motor vehicles are an important part of urban road traffic system, which plays an important role in the daily travel of urban residents. In recent years, the congestion of urban road traffic system has become more and more serious. In order to alleviate the congestion situation, on the one hand, the traffic management department reduces the road congestion by limiting the number of motor vehicles; on the other hand, the government vigorously advocates public transportation and green and low-carbon travel to adjust the travel mode structure. This paper systematically combs, summarizes and summarizes the views of domestic and foreign scholars from two aspects of the mode and theoretical development of non-motor vehicles turning left across the street. It is found that the left-turn crossing behavior of non-motor vehicles is from simple to comprehensive, from immature to gradually mature. Finally, the research on the development of non-motor vehicle holiday behavior is summarized and prospected.

Keywords: Non-motor vehicle left turn crossing behavior, Crossing mode analysis.

1. Introduction

Intersection is the main location of non-contradiction, and its traffic efficiency directly affects the running quality of urban traffic system. In previous urban planning, the right of way of non-motor vehicles at intersections was usually bound with the right of way of pedestrians (crossing the street together with pedestrians, and crossing the street twice when turning left). However, with the sharp increase in the number of non-motor vehicles (especially electric bicycles), the design of improving the capacity of non-motor vehicles has been proposed by more and more people, which has been applied in Beijing, Fuzhou, Baoding and other cities, non-shared left right-of-way (non-motor vehicles and motor vehicles turn left at the same time, a street crossing) is a representative form of innovation.

Obviously, shared left turn traffic can significantly improve the traffic efficiency of non-motor vehicles and reduce the mixed pressure of non-motor vehicles and pedestrian flow across the street, so in practice, non-motor vehicles can often be observed in urban intersections that prohibit non-motor vehicles from turning left and have left turn phase dedicated to motor vehicles. However, due to the lack of relevant norms and considering the difficulties brought by practical applications, such as rigid phase sequence, non-motor vehicle emptying delay, pedestrian illegal mixed oblique and non-simultaneous left turn space safety and a series of problems, many cities are still cautious about shared left turn traffic, preferring to choose a more stable non-motor vehicle secondary street crossing form.

Due to its convenience, environmental protection, punctuality, low cost and other characteristics, non-motor vehicles play a pivotal role in urban short-distance commuting, daily travel, express delivery and takeout distribution. According to the statistics of the China Bicycle Association, as of the end of 2019, China's bicycle society has nearly 400 million, of which nearly 300 million electric bicycles. Subsequently, how to balance the relationship between the use of non-motor vehicles and motor vehicles to the limited right of way, so as to achieve the goal of reducing congestion and pollution has become the key of research.

In general, whether to promote left turn crossing of non-motor vehicles is still in the exploratory stage, and the lack of relevant research makes the theoretical basis scarce. Therefore, it is of great research value to carry out modeling and analysis of non-motor vehicle left turn crossing behavior at urban road intersections and explore the influencing factors and implementation conditions of non-motor vehicle left turn, which can provide key theoretical support for the formulation and implementation of non-motor vehicle left turn policy.

2. Analysis of Three Ways of Crossing the Street by Non-motor Vehicles

The current Traffic Signal Control Guidelines in Germany stipulate three basic types of non-motor vehicle signal control, namely integrated control with motor vehicle traffic, dedicated non-motor vehicle signal control in front of the conflict zone, and integrated control with pedestrian traffic. Therefore, with reference to the provisions of the "Traffic Signal Control Guide", the non-motor vehicle crossing mode at the signal intersection is divided into three types, namely the traditional crossing mode (left turn crossing once), the backward crossing mode of the parking line and the secondary crossing mode.

2.1. Analysis of traditional street crossing mode

Figure 1 shows the traditional street crossing of non-motor vehicles. The traditional way of crossing the street means that when the local green light is on, non-motor vehicles and motor vehicles jointly use the green light to go straight and turn left at the same time. At this time, several traffic flows that interfere with each other at the intersection produce traffic conflicts, including the conflict between the straight-going motor vehicle and the left-turning motor vehicle and the left-turning non-motor vehicle, the conflict between the straight-going non-motor vehicle and the left-turning non-

motor vehicle and the left-turning motor vehicle. The traditional way of crossing the street makes full use of the intersection time and space, reducing the signal cycle time, but also has obvious disadvantages, that is, non-motor vehicles and local and opposite direct motor vehicles have conflicts, easy to scratch, reduce traffic safety and traffic efficiency. The traditional crossing mode is suitable for the signal-controlled intersections with non-mixed traffic and no non-motor vehicle signal lights. This kind of crossing is more common in two-phase signalized intersections or non-signalized controlled intersections.

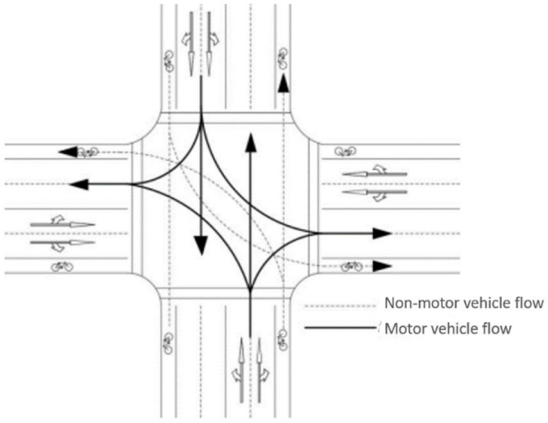

Figure 1. Non-motor vehicles traditional street crossing diagram

2.2. Analysis of the way the parking line moves back across the street

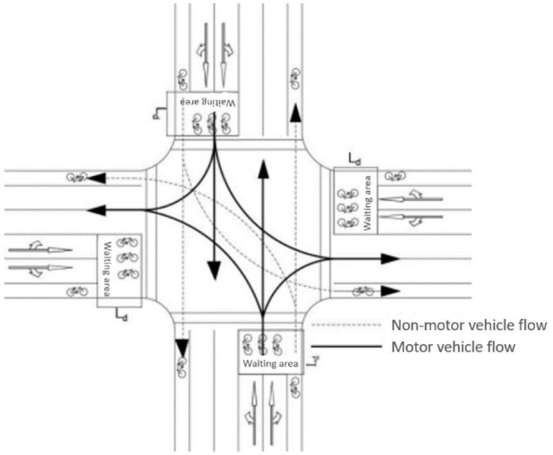

Figure 2. Non-conflict diagram of vehicle parking line moving back across the street

Figure 2 shows the non-conflict diagram of the vehicle parking line moving backward across the street. The traffic conflict between motor vehicles and non-motor vehicles in the mode of moving behind the stop line across the street can be divided into two stages. The first stage is when the non-motor vehicles are released in the waiting area, the motor vehicles will follow, and the non-motor vehicles will quickly pass through the intersection. At this stage, the motor vehicles have not passed the waiting area, and no non-motor conflicts will occur in this stage. The second stage is the completion of the release of non-motor vehicles in the waiting area. At this time, the motor vehicles have followed the group of non-motor vehicles and started to cross the intersection, and the non-motor vehicles in the original non-motor lane will produce traffic conflicts with motor vehicles, which is similar to the traffic conflicts in the traditional way of crossing the street. Since a certain number of non-motor vehicles are released in advance in the waiting area of non-motor vehicles, during which non-motor vehicles quickly cross the intersection, the number of vehicles causing non-conflict will decrease. Therefore, this street crossing mode can effectively reduce the traffic accident rate and improve the street crossing safety of non-motor vehicles.

According to the characteristics of non-motor vehicles starting fast and cyclists rushing through the intersection, the non-motor vehicle parking line is drawn before the motor vehicle entrance road, so that the motor vehicle parking line is moved back and is located after the non-motor vehicle waiting area. When the green light is on, the non-motor vehicle first enters the intersection, because the non-motor vehicle starting speed is fast and very flexible, so the time difference of the non-motor vehicle starting wave is ignored. When non-motor vehicles enter the intersection, the motor vehicles follow the group of non-motor vehicles through the parking line and move to the waiting area. The way of moving behind the parking line of motor vehicles avoids the conflict and interference between the main flow of non-motor vehicles and motor vehicles at the initial green light, and improves the traffic capacity of non-motor vehicles to a certain extent. Therefore, when the flow of non-motor vehicles is large, this way of crossing the street has obvious advantages.

2.3. Analysis of secondary street crossing mode

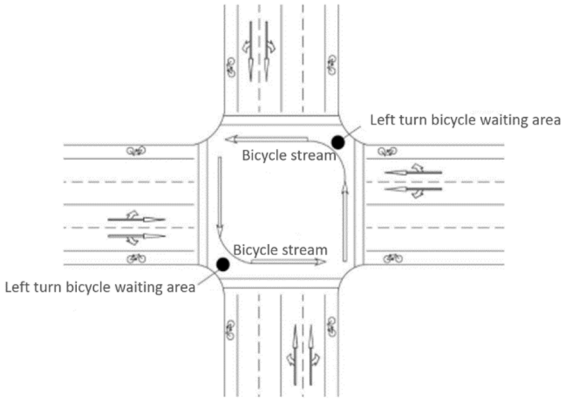

Figure 3. Non-motor vehicle secondary street crossing mode

The second crossing mode of non-motor vehicles is that when the phase green light is on, the non-motor vehicles turn left and go straight to the waiting area of the intersection, and then go straight through the intersection when the next phase green light is on, instead of directly turning left through the intersection, the non-motor vehicles turn left once and go straight twice. Figure 2-3 shows the second crossing of a non-motor vehicle. In the conventional signalized intersection, the secondary street crossing is a more common way. This street crossing mode sacrifices the traffic efficiency of non-motor vehicles in exchange for improving the safety of non-motor vehicles across the street, avoids traffic conflicts between left-turning non-motor vehicles at two-phase signal intersections and straight-going motor vehicles and right-turning motor vehicles at their own phase, and improves the traffic efficiency of motor vehicles at the expense of the traffic efficiency of left-turning non-motor vehicles. The way of crossing the street is suitable for the situation that both the intersection machine and the non-traffic flow are large. At this time, the implementation of secondary crossing will

effectively improve the passing speed of motor vehicles and the safety of non-motor vehicles.

At a typical two-phase signal controlled intersection, the conflict between left-turning non-motor vehicles and straight-going vehicles is one of the most serious traffic conflicts at the intersection. The second crossing of the street changes the traffic pressure of left-turning non-motor vehicles placed on straight-going vehicles into the collision impact of straight-going non-motor vehicles on right-turning vehicles. Second crossing of the street by non-motor vehicles reduces the traffic conflicts between left-turning non-motor vehicles and local and opposite straight-going vehicles, as well as right-turning vehicles, leaving only the conflicts between straight-going non-motor vehicles and right-turning vehicles, which greatly improves the safety of non-motor vehicles crossing the street.

Since the second crossing mode increases the waiting time of the left-turning non-motor vehicle for the signal, and the driving distance of the left-turning non-motor vehicle in the intersection is also slightly longer than that of the direct left-turning mode compared with the traditional crossing mode, the traffic efficiency of the left-turning non-motor vehicle will be reduced.

3. Research and Development of Left Turn Crossing of Non-motor Vehicles

3.1. Research and development of left turn crossing of non-motor vehicles in China

People, vehicles, roads and environment constitute the four elements of road traffic. In these four elements, people are the main body of traffic, the car depends on people to drive, the road depends on people to use, and the traffic is generated in a certain environment. Different people and different modes of transportation will show different traffic behaviors, which increases the complexity of modern traffic, and thus produces the research on road traffic psychology. As the concrete application and embodiment of the content of psychology in road traffic, road traffic psychology has its own characteristics and laws, which need us to use the correct method to find these characteristics and laws, so as to take corresponding measures to solve them. Therefore, it is of great significance to understand and master certain research methods, whether it is for the research of the discipline itself or for the application of theory and practice.

In "Five Methods of Road Traffic Psychology Research" [1], it is introduced that the research on the behavior law of traffic offenders mainly adopts five methods: observation method, experiment method, tracking research method, psychological measurement method and quantitative statistical analysis method. Wang Feng [2] analyzed the traffic conflict between left-turning non-motorized traffic flow and motorized traffic flow at intersections. In order to solve this problem, this paper draws on the theoretical research results of traffic conflict technology (TCT) at home and abroad, puts forward the method of non-motor vehicle left turn, establishes the conflict model, and theoretically proves that "second turn" can reduce traffic conflict and improve the safety of intersection. It has a strong guiding significance for intersection design and reconstruction. Zhang Wenkai [3] first studied the two ways of turning left by non-motor vehicles at intersections and found that turning left once across the street is still a feasible and efficient way of traffic organization, although it has certain limitations. Then, the application conditions of turning left once across the street are analyzed, and the slow priority non-motor vehicle signal timing method is proposed. Finally, an intersection in Beijing is taken as an example for simulation analysis. The results show that the left turn crossing scheme can make full use of the time and space resources of the intersection, reduce the total vehicle delay in the intersection, and significantly improve the operation efficiency of the left turn of the non-motor vehicle. Song Lang, Wang Jian, and Yang Binyu [4] set up a mixed integer nonlinear programming optimization model based on the optimization goal of maximizing vehicle traffic at intersections, and converted it into a nonlinear model for easy solution. VISSIM simulation was used to verify the operational benefits of the three schemes. The results show that, compared with the conventional design, the two-step crossing and the innovative design can improve the vehicle capacity at the intersection, and the congestion improvement effect is better in the high-traffic scenario, which can reduce the vehicle delay by 55.58% and 57.18%, respectively. The conventional design is not suitable for the scene with large flow of vehicles going straight, and the two-step crossing and innovative design are not suitable for the scene with large flow of vehicles turning left. The conventional design and the increase of left-turning non-motor vehicle flow across the street will lead to the rapid decline of motor vehicle capacity, while the innovative design is less affected by the left-turning non-motor vehicle flow and has better applicability in various traffic scenarios. Liu Shijie [5] based on the discussion of the organization form of left turn of non-motor vehicles at intersections, and aiming at the more typical form of direct left turn of non-motor vehicles and motor vehicles in the same phase, he established a model of the shortest distance between motor vehicles' running tracks. Considering the influence of the left-turning lane width, green belt width, center line offset and other parameters on the left-turning trajectory of motor vehicles, the intersection conditions for non-motor vehicles to turn left safely are obtained. Through the actual case analysis, the intersection optimization and improvement measures are put forward.

Aiming at the organization method of left turn in non-motor vehicles, Yang Zisong [6] studied the two methods of turning left in non-motor vehicles with green light first and setting the phase of turning left only for bicycles, and discussed their applicable conditions, advantages and disadvantages. Chen Xiaoming et al. [7] established a vehicle capacity model under the influence of non-motor vehicles, and studied the impact of non-motor vehicles' secondary crossing on the operation efficiency of signalized intersections. Yang Xiaoguang [8] used two indicators of vehicle capacity and traffic equivalent conflict to evaluate the two modes of bicycle left turn crossing once and twice at two-phase and four-phase intersections. However, the calculation model of traffic equivalent conflict was relatively simple and could not accurately reflect the safety status of each mode. Zhao Jing [9] studied the loss of traffic capacity of motor vehicles caused by non-conflict in two modes of turning left by bicycle, one crossing the street and two crossing the street.

3.2. Research and development of left turn crossing of non-motor vehicles in foreign countries

Smith[10] and Opielal[11] et al. calculated the running speed and speed distribution of non-motor vehicles under

different conditions and scenarios. Botma and Papendrecht[12] explored the correlation between the average speed of non-motor vehicles and their queue length based on measured data samples. Karim and Tarek et al. [13] explored the relationship between traffic conflict and collision, and established a model to evaluate intersection safety level on the basis of analyzing the factors affecting the conflict. Plotkin and Komornick[14] obtained key information such as the types of accidents with high frequency and the time of accidents according to the distribution of accidents in the study area according to the month and place of traffic accidents, and calculated the safety spacing of non-traffic traffic. Chen Xiaoming et al. [15] established a model of the impact of non-motor vehicles on motor vehicle capacity by using traffic wave theory, considering riders' psychology and non-motor vehicle characteristics in the second crossing mode at intersections. Allen[16] investigated several large signalized intersections in the United States, explored the relationship between non-motor vehicle traffic volume and traffic conflict, and quantified the impact of non-motor vehicles on motor vehicles. Through the analysis of intersection video data, Raksuntorn W analyzed traffic characteristics such as bicycle speed, acceleration and deceleration, starting loss time, arrival distribution and acceptable clearance entering and leaving the intersection, and fitted the relationship between these characteristics with a generalized linear model [17][18]. Chen J[19] analyzed the conflict between vehicles, bicycles and pedestrians at the intersection, studied the impact of the conflict on the intersection capacity, and established the critical volume model for setting the left turn bicycle phase and the time model for ending the bicycle and pedestrian phase in advance.

4. Summary and Prospect

Through the systematic review of literatures and documents related to left-turn crossing behavior of non-motor vehicles at home and abroad, it is found that no matter the viewpoints from domestic and foreign academic circles or the understanding of legal provisions in Europe and the United States, they all go through a similar process, that is, from simple to comprehensive, immature to gradually mature development process.

After long-term development, China has gradually paid attention to non-motor vehicle street crossing, and China has become a veritable transportation country. The achievement of excellence in the field of transportation is inseparable from the research of thousands of transportation scholars. At present, at intersections of domestic cities, the phenomenon of left turn traffic integrating non-motor vehicles and vehicles with the same direction has been adopted, but there is no clear relevant specification for whether the intersection is set up with a left turn crossing of non-motor vehicles. The setting of a left turn crossing of non-motor vehicles can only be designed according to the actual situation and local conditions. There is a lack of reasonable index to evaluate and define the scope of application for the designed left turn crossing of non-motor vehicles.

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