Frontiers in Traffic and Transportation Engineering (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/ftte.2024.040103
ISSN 2616-2334 Vol. 4 Num. 1

A Study of Safe Left-Turn Intersection Conditions for Non-Motorized Vehicles in Lhasa Based on Expansion Widths

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Keywords: Non-motorized, Expansion Width, Intersection, Shortest Distance, Multiple Linear Regression

Abstract: Nowadays, the safe and unimpeded traffic plays a vital role in the development of Lhasa. Non-motor vehicles play an increasingly prominent role in the traffic. In this paper, the shortest distance and multiple linear regression methods are used to construct the left-turn non-motorized flow expansion width model and the relationship model of the left-turn non-motorized expansion width influencing factors for research. The results showed that the conditions for safe left-turning of non-motorized vehicles at intersections in Lhasa are non-motorized vehicle direction of travel and speed inhomogeneity characteristics, signal phasing situation, non-motorized lane width and the number of left-turning non-motorized vehicles, of which the number of left-turning non-motorized vehicles is the main factor. When the number of left-turning non-motorized vehicles is within a certain number, and its maximum expansion width does not exceed the theoretical value, non-motorized vehicles in the intersection can safely turn left, otherwise the possibility of causing traffic conflicts is greatly increased. The results of the study provide theoretical references for ensuring traffic safety at intersections in Lhasa, promoting the modernization of Xizang's transportation construction as well as transportation development.

1. Introduction

In recent years, the increasing proportion of non-motorized travel has also led to increasingly prominent traffic problems at road intersections, while non-motorized vehicles at intersections are characterized by high traffic flow, riding randomness, and frequency of violations, so the study of safe left-turn conditions for non-motorized vehicles at intersections considering the expansion of widths is particularly important.

Nowadays, scholars have done many researches on the safety of non-motor vehicles passing through intersections. Li Haonan et al. proposed a spatial optimization strategy for non-motorized traffic at urban signal intersections in Nanchang City based on investigating the current status of non-motorized traffic at signal intersections in Nanchang City and analyzing the non-motorized traffic flow and conflict situation[1]. Cui Hongjun et al. analyze the behavioral characteristics of straight-line non-motorized vehicles under expansion characteristics, construct a conflict risk evaluation system for straight-line non-motorized vehicles at signalized intersections, and propose a non-motorized vehicle conflict risk entropy calculation method based on improved entropy weight method, which provides certain references for the research of non-motorized vehicle conflict risk at signalized intersections [2]. Pengfei Zhao et al. statistically described left-turn e-bike traffic parameters such as left-turn e-bike flow rate per unit expansion degree, left-turn e-bike traffic density, and left-turn e-bike vehicle speed, and quantitatively analyzed the impact of e-bike traffic flow characteristics at intersections on their expansion degree [3]. Zhang Yidan et al. analyzed the extent to which nine factors, including right-turning motor vehicle traffic volume, left-turning non-motorized vehicle ratio, direct non-motorized vehicle traffic volume, pedestrian traffic volume, and e-bicycle ratio, affect the width of the expansion of the direct non-motorized vehicle flow [4]. Yang et al. constructed a stochastic parametric Poisson traffic conflict model to analyze the relationship between left-turn speed, left-turn traffic volume, left-turn spacing, center circle, left-turn guideway for motor vehicles and traffic conflict for left-turning non-motorized vehicles [5]. Zhou Zhiwen et al. constructed an expansion conflict number model for left-turning non-motorized vehicles and left-turning motorized vehicles in the same inlet lane to obtain the capacity impact coefficients of left-turning motorized vehicles under different maximum lateral travel widths of left-turning non-motorized vehicles [6]. Zhang Xu et al. studied and analyzed the factors affecting the width of non-motorized expansion as the number of bicycles, the number of electric bicycles, the number of pedestrians crossing the street, the directional inhomogeneity coefficient, the width of non-motorized lanes, and the flow rate of motorized vehicles, which provides a theoretical basis for the improvement of the intersection's accessibility and the city's management planning [7].

At present, in the face of the special environment of the Xizang region, there is a lack of research to a certain extent to consider the conditions of safe left-turning of non-motorized vehicles at intersections with swollen widths. By collecting a large number of researches of scholars on the safe passage of non-motorized vehicles through the intersections, we analyze the conditions of safe left-turning intersections of non-motorized vehicles that better meet the conditions of safe left-turning intersections of Lhasa City, such as the direction of non-motorized vehicle travel and the speed of the non-uniformity of the characteristics, the situation of the signal phases, the width of non-motorized lane and the number of left-turning non-motorized vehicles. Based on the expansion width of left-turning non-motorized vehicles at intersections, this paper studies the influencing factors of the expansion width of left-turning non-motorized vehicles and constructs an expansion width model applicable to Lhasa City to calculate the maximum expansion width, which is actually applied to an intersection in Lhasa City to calculate the maximum expansion width of its left-turning non-motorized vehicles. The conditions and maximum expansion width of safe left-turn intersections for non-motorized vehicles studied in this paper provide theoretical references for the modernization of urban traffic in Xizang.

2. Left-turn non-motorized expansion width study

2.1 Analyze left-turn non-motorized expansion widths

The non-motorized expansion width is the lateral occupancy width of the trajectory of non-motorized traffic within a city roadway intersection when there is non-motorized traffic moving through it. In the traditional urban intersections, there are three kinds of non-motor vehicle tracks: straight, left-turn and right-turn. And the left-turn non-motorized expansion width is the lateral occupancy width of the left-turn non-motorized flow trajectory when the intersection left-turn signal phase is released, as shown in Figure 1.

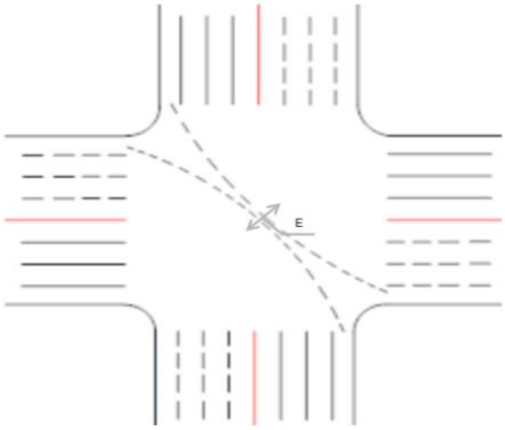

Figure 1. Chart of maximum expansion widths for left-turning non-motorized vehicles

Usually due to the starting point of each non-motorized vehicle start reaction time is different, non-motorized lanes are narrower, the number of vehicles as well as non-motorized vehicles rush each other or avoiding factors such as the impact of the expansion of the width of the presentation of the two ends of the narrow, wide in the middle of the situation, and the maximum expansion of the width of the non-motorized flow refers to the non-motorized flow of the maximum width of the lateral occupancy, generally appearing in the middle of the entire left-turn non-motorized flow area.

2.2 Left-turn non-motorized vehicle expansion width model construction

Taking a conventional four-lane intersection as an example, a left-turn non-motorized flow expansion width model is constructed based on relevant research literature to calculate the maximum expansion width [8]. It is assumed that when the left-turn signal phase passes within the intersection and forms a stable left-turn non-motorized flow, three points m_1, m_2, and m_3 are set up for the maximum expansion width segment that occurs for the non-motorized flow, and m_1 and m_2 are the coordinate points on both sides of the left-turn non-motorized flow in the segment, respectively.

Construct the plane rectangular coordinate system, connect the origin O and m_1 point and extend, set the equation of the line for $y = kx$, from m_2 point for perpendicular to the line of the vertical line, intersecting at the point m_3, m_3 for the non-motorized flow of the maximum expansion of the width of the center of the intersection by the side of the point, l_{13} for the maximum expansion of the width of non-motorized flow of the maximum expansion of the width of the width of the non-motorized flow of the intersection, as shown in Figure 2.

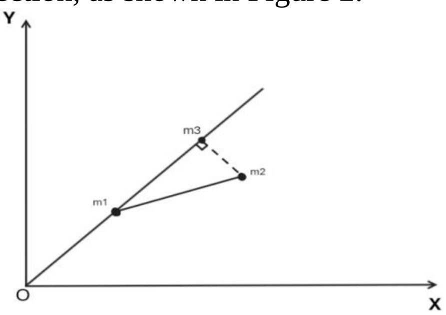

Figure 2. Coordinate diagram for calculating the maximum expansion width for left-turning non-motorized vehicles

The distance l_{12} between points m_1 and m_2 can be found based on the formula for the shortest distance between two points.

$$l_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{1}$$

Substitute the coordinates of the point m_1 into this linear equation.

$$y = kx = \frac{y_1}{x_1} x \tag{2}$$

The shortest distance l_{23} between points m_2 and m_3 can be calculated from the figure.

$$l_{23} = \frac{kx_2 - y_2}{\sqrt{k^2 + 1}} = \frac{y_1 x_2 - x_1 y_2}{\sqrt{(x_1^2 + y_1^2)}} \tag{3}$$

From l_{12} and l_{23}, the distance l_{13} between points m_1 and m_3 can be obtained. Because the maximum expansion width of non-motor vehicle $E = l_{13}$, the maximum expansion width E can be obtained.

$$E = l_{13} = \sqrt{l_{12}{}^2 + l_{23}{}^2} \tag{4}$$

$$E = l_{13} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 - \frac{(y_1 x_2 - x_1 y_2)^2}{(x_1^2 + y_1^2)}} \tag{5}$$

3. Analysis of safe left-turn intersection conditions for non-motorized vehicles in Lhasa City

The non-motor vehicles' non-uniformity of driving direction and speed at left-turn intersection is caused by the non-motor vehicles' behavior of racing or avoiding each other when the left-turn signals are released, which results in the non-motor vehicles' driving direction deviating from the original left-turn traffic trajectory to a small extent, different drivers have different driving behavior and their own characteristics, so that the driving speed of each non-motor vehicle has different impact on the left-turn non-motor vehicle expansion width.

Signal phase changes in different cycles will affect the trajectory of non-motorized vehicles in the intersection to a certain extent, when there is a straight and left-turn signal phase at the same time release, non-motorized vehicles to make a safe left turn in a second crossing and only the formation of straight non-motorized vehicles expanding the width of the street, while there is a separate release of the left-turn signal phase, the non-motorized vehicles can be completed by a single crossing to make a safe left turn, and at the same time there will be a left-turn non-motorized vehicle expansion width.

The setting of the non-motorized lane width affects the space available for left-turning non-motorized vehicles. If the non-motorized lane is narrow, the non-motorized vehicle may feel congested during the initiation of a left turn, resulting in an unstable trajectory, which in turn affects the travel path and expansion width of the left-turning non-motorized vehicle.

The number of left-turning non-motorized vehicles has a more pronounced effect on the width of the swell generated by their traffic. When the number of non-motorized vehicles is low, the vehicles have sufficient riding space between each other and do not interfere with each other significantly, so the maximum expansion width value for left-turning non-motorized traffic at the intersection is small. However, when the number of non-motorized vehicles increases to reach a certain value, the space for non-motorized vehicles to travel is limited, and the left-turn path of non-motorized vehicles may create more uncertainty, so a larger expansion width is needed to ensure safe left-turns for non-motorized vehicles at the intersection.

4. Modeling and Example Analysis of the Relationship between Factors Influencing the Width of Left-Turn Non-Motorized Expansion

4.1 Analyzing multiple linear regressions

Through several investigations and analyses of several intersections in Lhasa City, it can be preliminarily concluded that the influencing factors of the maximum expansion width of left-turning non-motorized vehicles are the non-motorized vehicles' traveling direction and speed non-uniformity characteristics, the signal phase situation, the width of the non-motorized lanes and the number of left-turning non-motorized vehicles. Among the four factors, the uncertainty of non-motor vehicle's direction and speed is too large and difficult to estimate. The intersection signal phasing situation only has a separate left-turn signal phase to produce the left-turn non-motorized expansion width. Therefore, a multiple linear regression model was established with non-motorized lane width and the number of left-turning non-motorized vehicles as the independent variables and maximum expansion width as the dependent variable to investigate the relationship between the maximum expansion width of left-turning non-motorized vehicles and these two influencing factors.

As a common statistical method, multivariate linear regression is mainly used to study the relationship between one dependent variable and many independent variables. The dependent variable studied in this paper is the maximum expansion width of left-turning non-motorized vehicles, and the independent variables are the width of the non-motorized lane and the number of left-turning non-motorized vehicles. Through regression analysis, a linear relationship between the dependent variable and the respective variables can be determined.

4.2 Relationship modeling of factors influencing the width of left-turn non-motorized expansion

Referring to the existing related literature, based on the method of scholars' research on the relationship between the expansion width and its influencing factors, combined with the analysis proposed in this paper to influence the maximum expansion width of the width of the non-motorized roadway and the number of left-turning non-motorized vehicles of the two influencing factors, through the assumption that the expansion width of the width of the Y, the width of the non-motorized roadway for the x_a, and the number of left-turning non-motorized vehicles for the x_b, and the establishment of the linear model of multiple regression[9-10].

$$Y = \beta_0 + \beta_a x_a + \beta_b x_b + \varepsilon \tag{6}$$

Where β_0 , β_1 and β_2 are regression coefficients, ε is the random error term, $\varepsilon \sim N(0,\sigma^2)$.

Its matrix form can be obtained from the above equation.

$$Y = \beta X + E \tag{7}$$

4.3 Example analysis

Taking certain intersections with separate left-turn signal phases in Lhasa City as an example, investigation and observation of these intersections are carried out to calculate the maximum expansion width of left-turn non-motorized vehicles at each intersection through the established left-turn non-motorized vehicle expansion width model, and to measure and count the width of the non-motorized lanes at the inlets of each intersection and the number of non-motorized vehicles before the release of the left-turn signal phases, as shown in Table.1.

Table.1. Statistical tables for the survey of left-turning non-motor vehicles at certain intersections in Lhasa

Serial number	Maximum expansion width	Non-motorized lane width/m	Number of non-motorized vehicles turning left
1	7.4983	2.1	32
2	5.6537	1.8	28
3	6.5972	2.0	31
4	7.5103	2.1	34
5	5.9062	2.0	29
6	7.6113	2.2	33

The data in the above table are brought into the relationship model of the factors affecting the left-turn non-motorized vehicle expansion width, and the relationship between the maximum expansion width and the width of the non-motorized lane and the number of left-turn non-motorized vehicles is analyzed by the method of multiple linear regressions, and the results are obtained as shown in Table.2.

Table.2. Regression analysis results table

	Non-standardized coefficient		Standardized coefficient	t	P	VIF	R^2	Adjustment of R^2	F
	B	Standard error	Beta						
A constant (math.)	-5.202	1.905	-	-2.731	0.072*	-	0.936	0.893	f=21.962 p=0.016**
Non-motorized lane width/m	1.687	1.849	0.264	0.912	0.429	3.934			
Number of non-motorized vehicles turning left	0.275	0.109	0.73	2.522	0.086*	3.934			
Results of linear regression analysis n=6									

Note: ***, **, * represent 1%, 5% and 10% significance levels, respectively.

As can be seen from Table 2, R^2 is the degree of fit of curvilinear regression, the R^2 value is 0.936 indicating a good fit, VIF value is the severity of multiple covariance, standard error = B/t value, standardization coefficient is the coefficient obtained after standardizing the data, the significance P-value of the F-test is 0.016**, which presents significance at the level indicating that there is a significant relationship between the maximum expansion width of the left-turning non-motorized vehicles and the width of the nonmotorized lane, there is a certain linear relationship between the number of left-turn non-motorized vehicles. The left-turning non-motorized vehicle P-value reaches 0.086*, then its effect on the maximum expansion width of left-turning non-motorized vehicles is more significant, while the non-motorized lane width P-value is 0.429, then its effect is at a lower level of significance.

The relationship model of factors influencing the width of left-turn non-motorized expansion can be obtained from the multiple linear regression analyses.

$$Y = -5.202 + 1.687 x_a + 0.275 x_b \quad (8)$$

In Lhasa City, the intersection of the non-motorized lane width size has been designed in the case of left-turning non-motorized vehicles safely through the intersection of the conditions need to meet the theoretical estimate of the left-turning non-motorized vehicles does not exceed the value of the maximum expansion of the width, and the number of left-turning non-motorized vehicles on the maximum expansion of the width of the impact of the more pronounced, and therefore to reach the non-motorized vehicles to safely left-turning by the above formula can be derived from the analysis. When the theoretical estimated maximum expansion width for left-turning non-motorized vehicles at Intersection 1 is 9 and the non-motorized width is 2.1m, the number of left-turning non-motorized vehicles is 38. The theoretical estimated maximum expansion width for left-turning non-motorized vehicles at Intersection 2 is 7. The number of left-turning non-motorized vehicles at a non-motorized width of 1.8m is 33, and so on can be derived as the maximum number of left-turning non-motorized vehicles consistent with safe left-turning by non-motorized vehicles, as shown in Table.3.

Table.3. Table of results of analysis of safety conditions for non-motorized left turns

Serial number	Theoretical maximum expansion width	Non-motorized lane width/m	Number of non-motorized vehicles turning left
1	9	2.1	38
2	7	1.8	33
3	8	2.0	35
4	9	2.1	38
5	8	2.0	35
6	9	2.2	38

5. Conclusion

The study of safe left-turn conditions for non-motorized vehicles at intersections is of great significance in ensuring traffic safety at intersections in Lhasa and reducing safety hazards at intersections, as well as in advancing the development of Xizang's transportation sector and the modernization of transportation construction. In this paper, based on the survey observation data of some intersections with separate left-turn signal phases in Lhasa City, we consider the left-turn non-motorized vehicle expansion width at the time of releasing left-turn signal phases, and study the safety conditions of non-motorized left-turns at intersections. The study and discussion found that non-motorized vehicle travel direction and speed inhomogeneity characteristics, signal phasing conditions, non-motorized lane widths and the number of left-turning non-motorized vehicles have a greater impact on the maximum expansion width of non-motorized left-turns as well as the safe left-turns at the intersections in Lhasa. By constructing the left-turn non-motorized flow expansion width model and the relationship model of the left-turn non-motorized expansion width influencing factors it was concluded that the number of left-turn non-motorized vehicles is the main factor influencing its maximum expansion width. When there is no single left turn phase in the signal cycle of an intersection, it is suggested to use the method of twice crossing the street to improve the safety of the left turn, and when there is a single left turn phase and the width of the non-motorized lane is unchanged, the number of left-turning non-motor vehicles is suggested to be within a certain safety threshold, so that the maximum expansion width does not exceed its theoretical estimate, which can satisfy the safe left-turning of non-motor vehicles and effectively reduce the occurrence of traffic conflicts at intersections. The expansion width of the left-turn non-motor vehicle studied in this paper still has some deficiencies and unconsidered factors, factors such as the left-turn traffic flow of motor vehicles and the space occupied by intersections will affect the expansion width of left-turn non-motor vehicles to a certain extent. Some intersections in Lhasa do not have non-motor vehicle lanes, in order to improve the model, it is necessary to investigate and observe the intersection and add other factors to the model. In this paper, the study on the safe left-turn condition of non-motor vehicles at intersections considering the expansion width of left-turn non-motor vehicles provides a research idea for improving the efficiency and safety level of non-motor vehicles at intersections, it is of great significance to the traffic improvement of intersections.

Acknowledgements

The authors would like to express their sincere gratitude for the financial support from the 2023 Central Support for the Reform and Development Funds of Local Universities Project: Innovation and Entrepreneurship Training Program for College Students (Project No. S202310694015; Project Category: Autonomous Region Level; Project Leader: Qiyan Yao) Fund.

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