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Research Article

Analysis of Path Distribution Characteristics and Safety Impact of Pedestrians Crossing in the Advance Right-Turn Lane

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Pedestrian crossing chaos has become one of the significant problems of urban traffic nowadays, and the irregular behavior of pedestrians affects traffic operation and regional safety to a certain extent. Aiming at the safety of pedestrian crossing in the advance right-turn lane, the pedestrian path deviation (PPD) is proposed to quantitatively describe the pedestrian crossing path deviation and analyze the impact of PPD on pedestrian crossing safety. With four advance right-turn lanes at an intersection in Qingdao as the investigation site, the spatiotemporal information of pedestrians and motor vehicles is collected to analyze the characteristics of pedestrian path distribution and the influencing factors of pedestrian crossing under the factors of traffic flow and environment. The pedestrian-vehicle conflict characteristics are analyzed from the perspective of conflict rate and deceleration-to-safety. The severity level of human-vehicle conflict is classified according to the cumulative frequency of safety deceleration, and the severity model of human-vehicle conflict based on ordered probit is established. The results show that buildings such as large shopping malls and transportation hubs have an attractive effect on pedestrians. Under the influence of unilateral buildings, the proportion of irregular use of pedestrian crosswalks reaches 46.9%. There is a significant positive correlation between pedestrian flow and PPD index, and the increase of pedestrian flow causes the aggravation of pedestrian path deviation. The results of the analysis of PPD with pedestrian-vehicle conflict rate and conflict severity show that the increase of PPD significantly increases the risk of pedestrian-vehicle conflict occurrence; in addition, motor vehicle speed and PPD have significant effects on the severity of pedestrian-vehicle conflict, and the increase of both vehicle traffic speed and PPD causes the aggravation of the severity level of pedestrian-vehicle conflict. Combined with the above findings, the PPD index has some value in quantifying pedestrian spatial violations as well as regional safety evaluation, and the findings can provide theoretical guidance for the establishment of traffic facilities.

1. Introduction

The advance right-turn lane is widely used in large urban intersections. By widening the exit lane and setting up a turning curve to facilitate right-turning vehicles to merge into the direct traffic on the left, right-turning vehicle delays can be effectively reduced, and the risk of collision between right-turning vehicles and the left-hand direct traffic can be reduced [1–3]. Compared with the general right-turn lane, most of the advance right-turn lanes are not signalized to increase the efficiency of vehicular traffic, but the increased turning radius, with vehicles often passing at higher speeds, significantly increases the risk of pedestrians crossing the street; some pedestrians use crosswalks unreasonably in order to get to their destinations faster, resulting in unreasonable use of crosswalks, a behavior that has a significant impact on pedestrian crossing safety [4–7]. Therefore, it is necessary to carry out in-depth research on the behavioral characteristics of pedestrians crossing in the advance right-turn lane.

Pedestrian traffic has long been an important part of traffic research, and some progress has been made on pedestrian crossings and pedestrian-vehicle conflicts at advance right-turn lanes. Human-vehicle conflicts triggered by unsafe behaviors are an important cause of traffic accidents [8]. Chen et al. and Chen et al. [9, 10] used the ratio method to analyze the danger of pedestrian crossing conflicts, combined with the number of pedestrian crowds, crossing speed,

Figure 1: Traffic survey sites.

crossing location, and other factors to analyze the conflict process between motor vehicles and pedestrians in both directions, and established a motor vehicle and pedestrian delay model based on the passage time. Liu [11] proposed a control method and verified with examples that the regional safety problem was improved by studying the traffic characteristics of motor vehicles crossing the pedestrian flow in the advance right-turn lane, comparing the characteristics of pedestrian and motor vehicle speed changes during pedestrian-vehicle conflicts, and aiming at minimizing the overall delay of pedestrians and motor vehicles. Wang [12] extracted the trajectory information of pedestrians and motor vehicles in conflicts, calculated conflict indicators to classify the severity level, established a regression model to analyze the conflict influencing factors, and built an evaluation model to analyze the area safety according to the results. Xiong et al. [13] established a random walk model and simulated the pedestrian walking direction using partial differential equations. Besides, the cellular automata model [14, 15], lattice gas model [16], the social force model [17], and the centrifugal force model [18] are frequently used in the simulation modeling of pedestrians. Hediyeh et al. [19] conducted a study on pedestrian differences and analyzed the effects of gender, age, number of pedestrians in the population, crosswalk length, and signal phase on pedestrian movement status to understand the impact of intersection characteristics on the pedestrian crossing at a micro level. Zhang [20] analyzed the conflict process between right-turning motor vehicles and pedestrians, clarified the right-of-way in the conflict as well as the operation mechanism, and quantified the conflict impact based on the microscopic characteristics of pedestrian-motor vehicle conflict with delay as an indicator. Qu et al. and Qu et al. [21, 22] established a normal distribution model of pedestrian overflow locations by collecting spatiotemporal information of pedestrians and analyzing it through field surveys for spatial violations of pedestrians and proposed suggestions for optimization measures based on the trajectory distribution characteristics. The study of pedestrian-vehicle conflict can be of great help to improve urban traffic signal optimization. Ren et al. [23] considered yielding to pedestrians and proposed a signal timing optimization method with superimposed phases and spatial and temporal separation of pedestrian-vehicle conflicts to substantially improve intersection throughput efficiency and reduce delays as well as associated emissions while reducing the risk of pedestrian-vehicle conflicts.

Most of the current studies on advance right-turn lane safety focus on pedestrian-vehicle conflicts and their impact on traffic operation efficiency, and the studies on pedestrian crossing behavior in the area, especially the crossing path, only stay on the qualitative description of the distribution, and lack of quantitative analysis to explore the impact of irregular pedestrian crossing behavior on traffic safety. Based on this, this paper statistically analyzes the distribution characteristics of pedestrian crossing trajectories under different traffic flow and environment conditions, proposes pedestrian path deviation index to quantify the distribution characteristics of pedestrian crossing, and studies the influence of pedestrian path on pedestrian crossing safety from two aspects of pedestrian-vehicle conflict rate and conflict severity to provide theoretical guidance for traffic safety evaluation and facility construction of urban level intersections.

2. Data Description

2.1. Observation Sites. The urban area is complex and diverse, and the environment of different areas may affect pedestrian crossing behavior [24]. Therefore, the selection of survey sites should consider land use, geometric design, and other factors. Through field investigation, an intersection in Qingdao, China, was selected for this study after careful consideration. This intersection consists of two main roads intersecting with advance right-turn lanes in each direction thus divided into four sites and similar in design form as shown in Figure 1. The observation time is 15 : 00-19 : 00. Since the survey site is surrounded by large shopping malls, subway stations, attractions, and other facilities, the effect of attracting foot traffic can effectively meet the needs of the study sample. The video material is area surveillance video, and the benefit of this method is to effectively reduce the impact of field erection intersections on the behavior of pedestrians.

2.2. Data Collection and Processing. After the recording of the video data was completed, the experimenter collected traffic information from the video. Combined with the field survey data, the experimenter needs to collect data on pedestrian flow, vehicle flow, average vehicle speed, pedestrian-

Table 1: Traffic survey data.

Site	Crosswalk length [m]	Crosswalk width [m]	Traffic flow [number]	Pedestrian flow [number]	Pedestrian-vehicle conflict [number]	Average vehicle speed [m/s]	Surrounding buildings
1	7.5	5	1504	1509	272	6.3	Metro, shopping malls
2	6	5	747	1463	77	6.9	Metro, shopping malls
3	6.5	5	555	1125	77	7.1	Metro, attractions
4	6.5	5	151	1282	110	7.2	Scenic spots (unilateral)

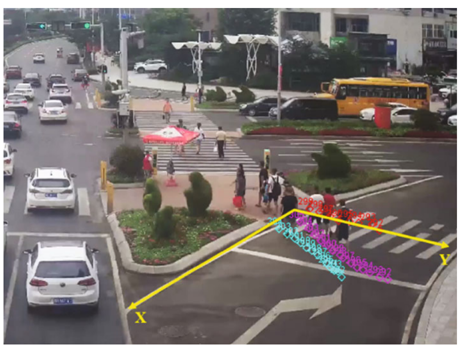

Figure 2: Coordinate system establishment and trajectory tracking.

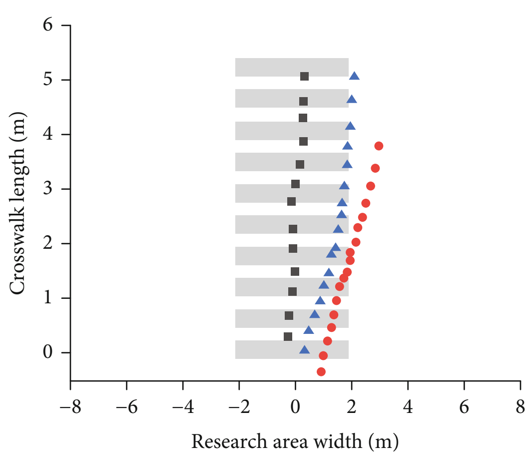

Figure 3: Coordinate transformation.

vehicle conflict, and geometric design information of the survey site, and descriptive statistics are shown in Table 1.

With regard to the collection of motion state and conflict information of traffic participants, this study uses Tracker software to process the video data and establishes the coordinate system in the software, as shown in Figure 2. The coordinate information of pedestrians and vehicles is obtained by tracking technology. The obtained image coordinates are transformed into world coordinates by homogeneous equations, as shown in Figure 3, and the pedestrian and vehicle motion state data are calculated. The experimental personnel will be trained before collecting data, including the identification of human-vehicle conflicts and the application of software, so as to minimize the error caused by the operation of the experimental personnel.

3. Distribution Characteristics of Pedestrian Paths

3.1. Path Distribution Characteristics. When pedestrians cross the advance right-turn lane, some pedestrians do not use or even use the crosswalk in order to reach the destination faster, which seriously affects the normal traffic operation, and at the same time, such behavior of pedestrians can be hazardous to their own safety [11]. In order to study the path distribution characteristics of pedestrians crossing the street at the advance right-turn lane more intuitively, a total of 400 pedestrian samples were sampled at 1-hour intervals for each location, the characteristics of pedestrian crossing locations were counted, and the heat map of pedestrian paths crossing the street was drawn as shown in Figure 4. As can be seen from the figure, the distribution of pedestrian crossing paths at different observation sites is obviously different. The pedestrian crosswalk at survey site 1 is shorter in length, the pedestrian crossing paths are more concentrated inside the crosswalk, and most of the pedestrians do not produce path deviation behavior when the crossing time is shorter (Figure 4(b)). Buildings with high population flow have a significant attraction effect on the paths of pedestrians crossing the street. Compared to other sites where the distribution of pedestrian paths is symmetrical about the crosswalk median ($x = 0$), pedestrian paths are skewed to one side due to the distribution of attractions and supporting facilities around site 4 on one side (Figure 4(d)). Irregular use of crosswalks is more serious. The chaotic path distribution of pedestrians crossing crosswalks directly leads to an increase in the range of conflict areas with motor vehicles, and different conflict point locations correspond to different traffic participant movement states, which significantly affects the severity of pedestrian-vehicle conflicts and requires further quantitative analysis.

3.2. Pedestrian Path Deviation. The paths of pedestrians will affect the safety of pedestrians crossing the street because the unreasonable use of pedestrian crossings

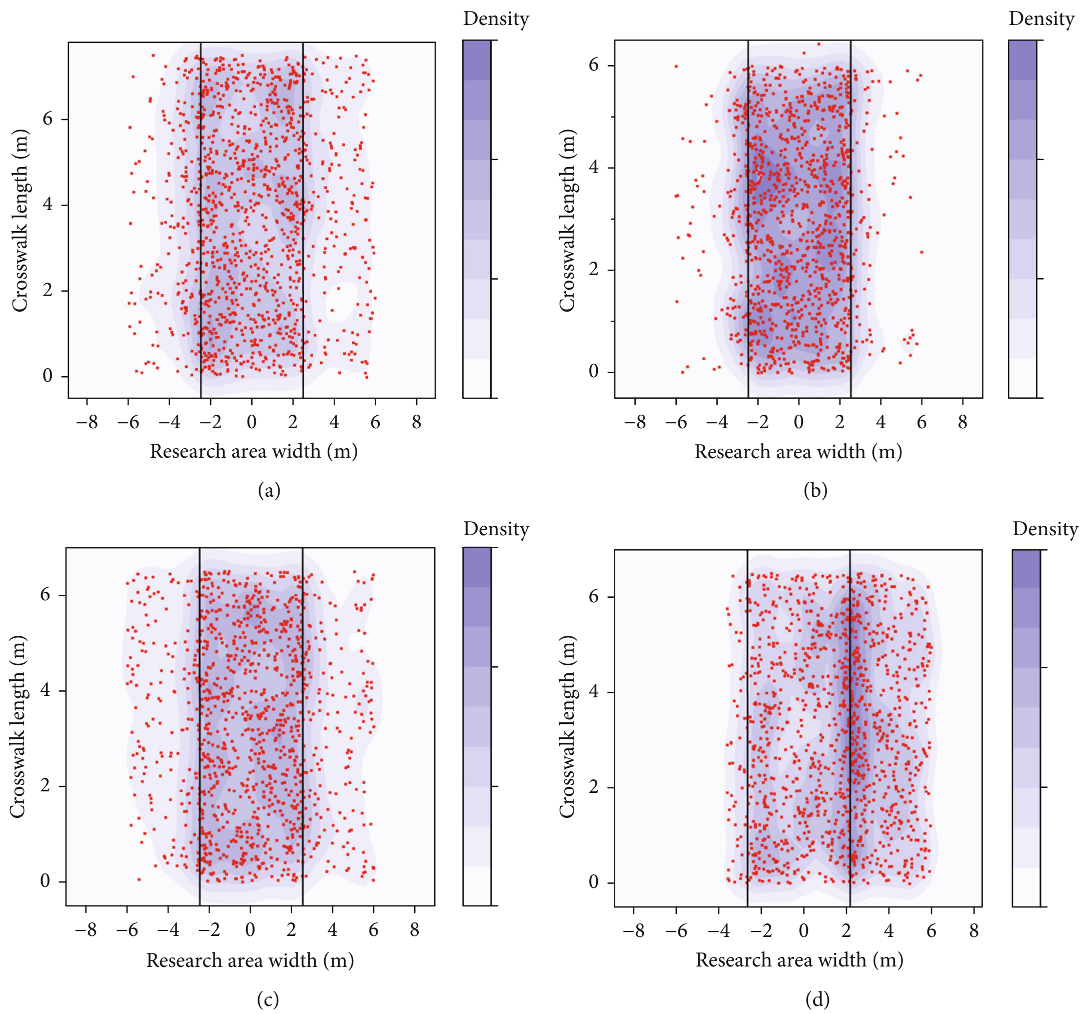

Figure 4: Heat map of pedestrian paths. (a) Site 1. (b) Site 2. (c) Site 3. (d) Site 4.

directly increases the conflict area with motor vehicles [25]. Current studies are mostly limited to the qualitative characteristics of pedestrian distribution [21]. In order to analyze more specifically the influencing factors of pedestrian paths and impacts on traffic safety, this paper will quantify the path deviation behavior of pedestrians when crossing streets. Firstly, the pedestrian crossing paths are divided into three categories: (1) pedestrian path is completely distributed within the crosswalk, defined as path type I, (2) pedestrian path is partially within the crosswalk, defined as path type II, and (3) path is completely not within the crosswalk, defined as path type III. Secondly, based on the coordinate system constructed in Figure 2, the pedestrian crossing path can be regarded as a straight line. The area enclosed by the pedestrian path and the boundary line of the pedestrian crosswalk and roadside sidewalk is defined as the path deviation area (ΔA), as shown in Figure 5. The expression for calculating the area of each type of path deviation area is shown in equation (1). Finally, this paper proposes pedestrian path deviation for quantitative analysis of pedestrian crossing path characteristics at the advance right-turn lane, which is calculated as (2).

$$\Delta A = \begin{cases} 0 & (\text{typeI}), \\ \int_{w/2}^{x_1} l - \dfrac{x - x_0}{x_1 - x_0} l dx, & (\text{typeII}), \\ \left(x_1 - \dfrac{w}{2}\right) \times l - \int_{x_0}^{x_1} \dfrac{x - x_0}{x_1 - x_0} l dx. & (\text{typeIII}), \end{cases} \tag{1}$$

$$\overline{\text{PPD}^{(k)}} = \frac{1}{n}\sum_{i=1}^{n} \text{PPD}_i = \frac{1}{n}\sum_{i=1}^{n} \frac{\Delta A_i}{A_o}. \tag{2}$$

where l is the length of the crosswalk, w is the width of the crosswalk, $(x_0, 0)$ is the coordinates of the pedestrian at the edge of the channelized island, (x_1, l) is the coordinates of the pedestrian at the edge of the sidewalk on the roadside, A_o is the crosswalk area, PPD_i is the pedestrian i path deviation, ΔA_i is the pedestrian i path deviation area, and $\overline{\text{PPD}^{(k)}}$ is the site k average pedestrian path deviation.

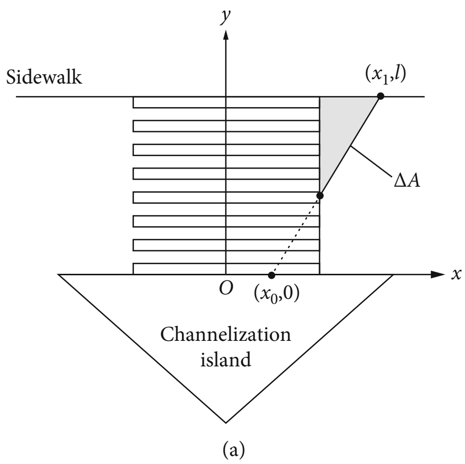

Figure 5: Path deviation area. (a) Type II. (b) Area III.

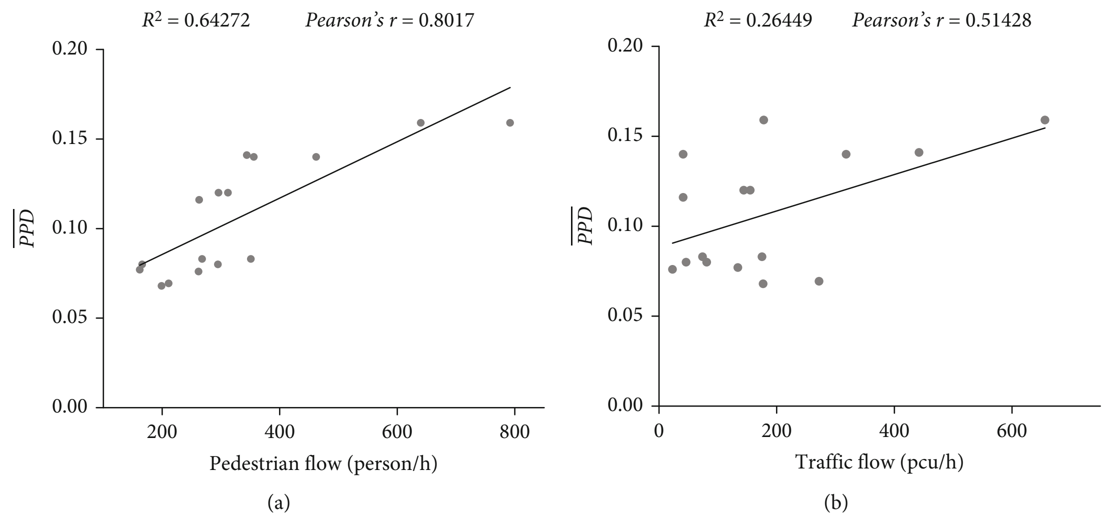

Figure 6: Analysis of the factors influencing PPD. (a) Pedestrian flow. (b) Traffic flow.

3.3. Influencing Factors of Pedestrian Path Deviation. The analysis in Section 3.1 on pedestrian path distribution characteristics shows that pedestrians are affected by traffic flow differences when crossing streets. We use the PPD index to quantitatively analyze the impact of pedestrian and vehicle traffic flow on pedestrian paths. The samples are divided into 16 groups with a time interval of 1 hour and then calculate the corresponding $\overline{\text{PPD}}$ index. The correlation between pedestrian flow, vehicle flow, and PPD indexes is analyzed separately by the linear fitting method, and the results are shown in Figure 6.

The Pearson coefficient between pedestrian flow and $\overline{\text{PPD}}$ is greater than 0.8, and the linear goodness of fit reaches 0.643, which proves that the PPD index is significantly and positively correlated with the pedestrian flow (Figure 7(a)). Pedestrians often cross streets in groups [16], and when pedestrian flow increases, pedestrians are influenced by their peers as well as the limitations of the crosswalk area, leading to an increase in the irregular use of pedestrian crossings. However, in Figure 7(b), the results prove that the effect of traffic flow on pedestrian crossing paths is not significant, probably because changes in traffic flow cause changes in different trends in vehicle spacing and speed, and the superimposed effect of the two effects is not obvious on pedestrian paths.

4. Pedestrian Crossing Safety Impact Analysis

The confusion of pedestrian crossing positions in the early right-turn lane directly leads to an increase in the area of pedestrian-vehicle conflict, which not only affects the probability of pedestrian-vehicle conflict. The severity of pedestrian-vehicle conflicts is also affected by the different speeds of vehicles at different moments when they pass through the right-turn lane [26]. Therefore, we analyze the characteristics of pedestrian-vehicle conflict in terms of both the probability of occurrence and the severity of the conflict and determine the relevant conflict indicators for the establishment of the pedestrian-vehicle conflict model.

4.1. Pedestrian-Vehicle Conflict Rate. Traditional safety evaluation generally uses the number of conflicts as a safety

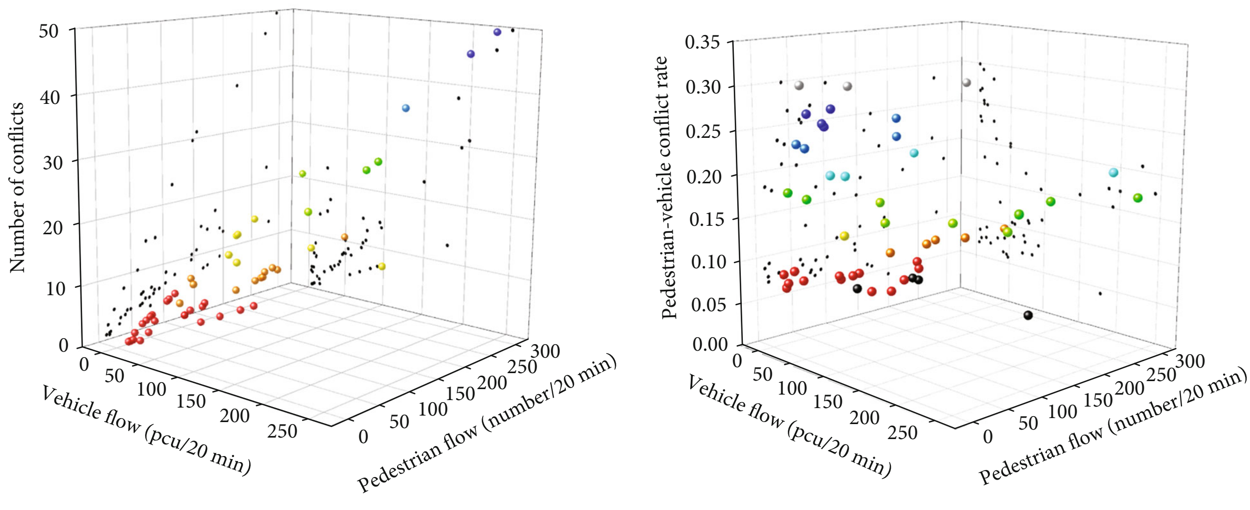

FIGURE 7: Impact of traffic flow on indicators. (a) Number of conflicts. (b) Pedestrian-vehicle conflict rate.

indicator [27], and the number of conflicts as an absolute number indicator is not suitable for horizontal comparison of multiple locations and time periods. Therefore, we use the human-vehicle conflict rate index for evaluation in order to reduce the influence of traffic flow, which is calculated as in equation (3). To prove that the pedestrian-vehicle conflict rate index has better representativeness in this experiment, the samples are divided into a total of 48 groups with a time interval of 20 min, the effects of pedestrian flow and vehicle flow on the number of conflicts and conflict rate are analyzed separately, and the results are shown in Figure 7.

$$R_{v-p}^{(k)} = \frac{T^{(k)}}{\sqrt{N_p \times N_v}}, \tag{3}$$

where $R_{v-p}^{(k)}$ is the traffic conflict rate between motor vehicles and pedestrians at site k, $T^{(k)}$ is the number of hourly traffic conflicts at site k, N_p is the number of pedestrian flows, and N_v is the number of vehicle flows.

From the projection of the data on the YZ and XZ planes in Figure 7(a), it can be seen that the number of conflicts is positively correlated with the volume of vehicles and pedestrian traffic, which is not applicable to the analysis of this paper because the size of this indicator is influenced by the traffic flow. Compared with the number of conflicts, the rate of pedestrian-vehicle conflicts can effectively reduce the interference caused by the differences in the vehicle and pedestrian flow when describing safety issues and can be used as a dependent variable to study the effect of PPD on pedestrian-vehicle conflicts (Figure 7(b)).

4.2. Deceleration to Safety. Conflict severity indicators are mainly divided into time indicators and speed indicators; in the case of multiple pedestrians and a motor vehicle conflict, the calculation of postencroachment time and time of conflict will be affected; so, this paper selects the speed indicator deceleration to safety (DST) as the conflict severity indicator. DST refers to the maximum acceleration value of the traffic participants to change their movement state to avoid conflict [28], the greater the DST value, the more serious the conflict. Since the pedestrian motion state is complex, while the motor vehicle motion state is easy to capture, the motor vehicle acceleration change value is taken as the DST value, and the DST value is derived from the coordinate information processed in the previous section according to equation (4) [12].

$$\mathrm{DST} = \max\left\{\left|\frac{2V_{\mathrm{pi}}\left(S_{\mathrm{pi}}V_{\mathrm{ci}} - S_{\mathrm{ci}}V_{\mathrm{pi}}\right)}{S_{\mathrm{pi}}^2}\right|\right\}, \tag{4}$$

where S_{ci} is the moment i motor vehicle distance from the conflict point, S_{pi} is the moment i pedestrian distance from the conflict point, V_{ci} is the moment i motor vehicle speed (m/s), and V_{pi} is the moment i pedestrian speed (m/s).

A total of 536 samples of pedestrian-vehicle conflicts are collected, which satisfies the minimum sample size of statistical principles. The distribution of DST at each site is shown in Figure 8. The DST values of pedestrian-vehicle conflicts at different observed sites are normally distributed in the interval of 1 ~ 8 m/s2. The average vehicle speed at site 4 is the highest, and accordingly, the mean DST value at site 4 is also at the highest level reaching 5.02 m/s2, exceeding the other sites by 28% on average. It can be concluded that an increase in the average motor vehicle speed significantly increases the severity of pedestrian-vehicle conflicts. However, in the analysis of the vehicle arrival rate and the mean DST, the correlation coefficient is only -0.48, indicating no significant influence relationship between the two indexes.

5. Pedestrian-Vehicle Conflict Model

In the previous analysis, the irregular use of pedestrian crosswalks has an impact on the probability and severity of

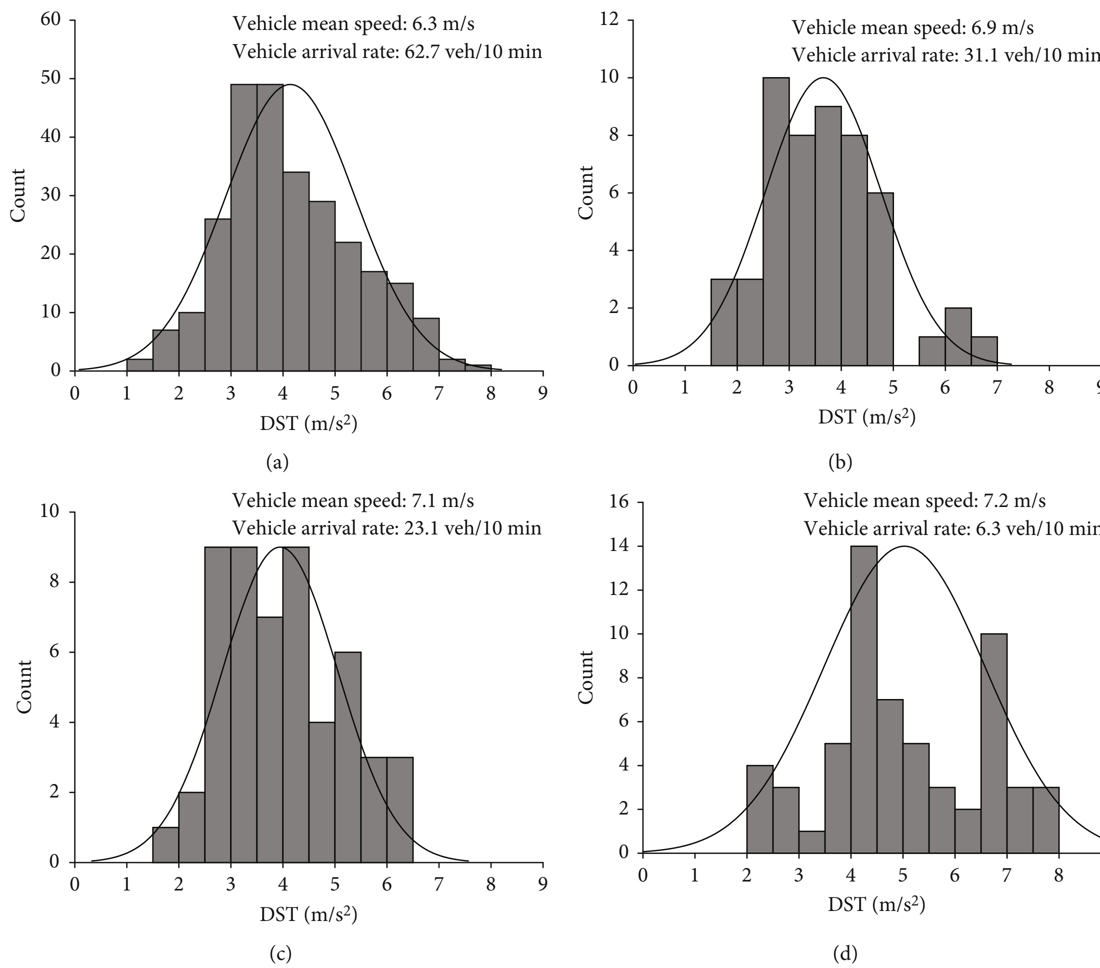

FIGURE 8: DST distribution. (a) Site 1. (b) Site 2. (c) Site 3. (d) Site 4.

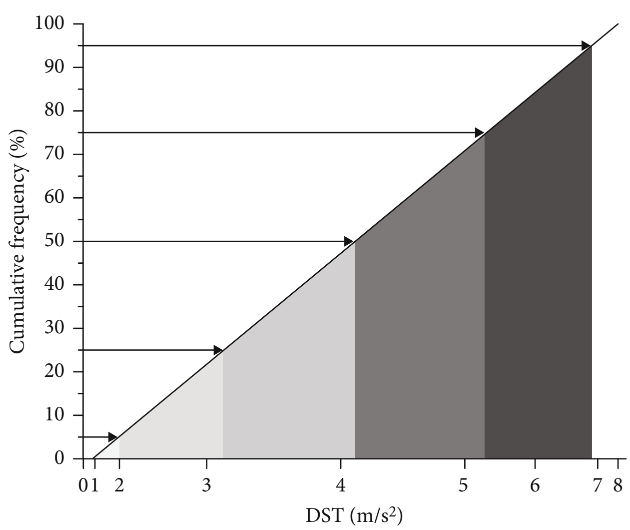

FIGURE 9: SPC grading result.

pedestrian-vehicle conflicts. Combined with the PPD index proposed in Section 3.2, the impact of pedestrian space violations on pedestrian-vehicle conflicts is quantitatively analyzed from the perspectives of pedestrian-vehicle conflict rate and DST.

TABLE 2: Traffic survey data.

	Crosswalk length	Vehicle speed	Vehicle arrival rate	PPD
Tolerance	0.134	0.297	0.811	0.569
VIF	7.49	3.363	1.233	1.757

5.1. Pedestrian-Vehicle Conflict Rate Model. In Section 4.1, it is proved that the pedestrian-vehicle conflict rate index is not affected by the difference in traffic flow in this experiment. Therefore, a linear model of the pedestrian-vehicle conflict rate and PPD is established to directly analyze the correlation between the two. The expression is shown in equation (5).

$$R_{v-p}^{(k)} = \alpha\overline{\mathrm{PPD}^{(k)}} + B, \tag{5}$$

where α is a coefficient and B is a constant.

5.2. Pedestrian-Vehicle Conflict Severity Model. The effectiveness of the DST index to describe the severity of pedestrian-vehicle conflict (SPC) has been recently confirmed in many studies [28, 29]. We divide the SPC levels according to the

Table 3: Conflict rate model results statistics.

Equation	Intercept	Slope	Residual sum of squares	Pearson's r	R^2
$y = a + b * x$	-0.09122 ± 0.0184	2.28544 ± 0.16817	0.05347	0.89476	0.79626

Table 4: Conflict severity model result statistics.

		Coefficient (β)	Standard deviation	Wald	Significance (p)
Factor	PPD	0.309	0.164	3.575	0.039**
	Crosswalk length	0.232	0.247	0.886	0.347
	Vehicle arrival rate	-0.002	0.004	0.232	0.63
	Vehicle speed	0.66	0.243	7.386	0.007**
Threshold value	μ_1	4.519			
	μ_2	5.527			
	μ_3	6.195			
	μ_4	6.925			
	μ_5	7.966			
Sample number = 536, LR chi^2(4) = 557.727, Prob > chi^2 = 0.000, pseudo R^2 = 0.092					

Note: ** is expressed in 95% confidence interval.

magnitude of the conflict's DST index and select the values corresponding to the cumulative DST distribution frequencies of 5%, 25%, 50%, 75%, and 95% as the grading thresholds for SPC = 1, 2, 3, 4, 5, and 6, respectively [30]. The larger SPC means the more serious human-vehicle conflict, and the SPC grading result is shown in Figure 9. A one-way ANOVA was performed on the DST index based on the conflict severity classification results, and a significance less than 0.05 was obtained, proving that DST is valid for the pedestrian-vehicle conflict severity classification.

In addition, the factors (independent variables) that contribute to the change in conflict severity are selected as crosswalk length, vehicle speed, vehicle arrival rate, and PPD. It is necessary to test for multicollinearity between the factors before regression analysis. The results of calculating the variable tolerances and variance inflation factors (VIF) are shown in Table 2, where all variables with tolerances > 0.1 and VIF < 10 satisfy the collinearity diagnostics.

The SPC index is transformed from DST, which has the same discrete characteristics and is normally distributed, and it also has the characteristic of hierarchical ordering, which satisfies the requirements of the ordered probit model for the dependent variable. The ordered probit model is a regression analysis model commonly used in statistics for ordered indicators, which can effectively derive the degree of influence of different factors and the threshold of change in the hierarchy of the dependent variable. Therefore, it applies to the study of the severity of pedestrian-vehicle conflict in this paper [31]. The model for the severity of pedestrian-vehicle conflict is as follows:

$$y^* = X\beta + \varepsilon, \tag{6}$$

where y is the dependent variable, y^* is the invisible or latent variable, X is the vector composed of explanatory variables, β is the coefficient of X, a vector composed of parameters to be estimated, indicating the magnitude of the influence of each explanatory variable on the explanatory variable, and ε is the random disturbance term, representing the sum of other factors that are ignored by the model but have an effect on the explanatory variable, the error term $\varepsilon \sim N(0, 1)$.

Let $\mu_1, \mu_2, \cdots \mu_6$ be the threshold value and $\mu_1 < \mu_2 < \cdots < \mu_6$, and we have

$$y = \begin{cases} 1, y^* < \mu_1, \\ 2, \mu_1 < y^* < \mu_2, \\ 3, \mu_2 < y^* < \mu_3, \\ 4, \mu_3 < y^* < \mu_4, \\ 5, \mu_4 < y^* < \mu_5, \\ 6, \mu_5 < y^*. \end{cases} \tag{7}$$

The SPC conditional probability is

$$\begin{aligned} P(y = 1|X) &= P(y^* = \mu_1|X) = \Phi(\mu_1 - \beta X), \\ P(y = 2|X) &= P(y^* = \mu_2|X) = \Phi(\mu_2 - \beta X), \\ &\vdots \\ P(y = 6|X) &= P(y^* = \mu_6|X) = \Phi(\mu_6 - \beta X), \end{aligned} \tag{8}$$

where $\Phi()$ is the density function of the standard normal distribution.

5.3. Model Results and Analysis. Using Origin to fit and analyze the conflict rate model and SPSS 26.0 to analyze the conflict severity model with ordered probability regression, the results are shown in Tables 3 and 4.

The slope of the linear model between the pedestrian-vehicle conflict rate and $\overline{\text{PPD}}$ is greater than 0, and the goodness of fit R^2 is 0.7963, which proves that it has a positive correlation with the regional pedestrian-vehicle conflict rate (Table 3). It can be seen from the model results that if the pedestrian crossing is not standardized, the $\overline{\text{PPD}}$ increases, and the probability of conflict between pedestrians and motor vehicles increases by about 23% for every 0.1 increase in $\overline{\text{PPD}}$ in advance right-turn lane. As a result, pedestrian crossing path deviation will seriously endanger their safety.

According to the results in Table 4, the factors affecting the severity of the pedestrian-vehicle conflict, PPD, and vehicle speed show significance ($P < 0.05$). The effect coefficients of PPD and vehicle speed on the SPC level are 0.309 and 0.66, respectively. This result suggests that the increase in PPD due to irregular pedestrian use of crosswalks to cross streets not only increases the probability of pedestrian-vehicle conflicts but also leads to an increase in the severity of pedestrian-vehicle conflicts. The speed of vehicles when crossing the advance right turn lane is also a significant factor causing an increase in the severity of pedestrian-vehicle conflicts. Excessive driving speed leads to the reduced reaction time for drivers as well as pedestrians, and the potential hazards are also rising sharply.

6. Conclusion

This paper investigates the characteristics of pedestrian crossing path distribution in the advance right-turn lane, analyzes the impact of pedestrian spatial violation crossing on traffic safety, proposes pedestrian trajectory deviation (PPD) to describe pedestrian crossing path characteristics, and establishes pedestrian-vehicle conflict rate and conflict severity model, with the following main findings.

(1) The pedestrian path deviation (PPD) index proposed in this paper can effectively reflect the impact of pedestrian spatial violations on crossing safety. In the results of model analysis, it was obtained that regional $\overline{\text{PPD}}$ was positively correlated with the rate of pedestrian-vehicle conflict ($\alpha = 2.285$), and PPD had a significant effect on the severity of pedestrian-vehicle conflict ($\beta = 0.309, P < 0.05$).

(2) The irregular use of pedestrian crossings and excessive speed of vehicles at advance right-turn lanes are serious hazards to traffic safety. For these reasons, roadside pedestrian guardrails or safety island greenbelts can be installed to limit pedestrian crossing path. In addition, the installation of speed limit signs or capture facilities on the side of the road to limit the speed of motor vehicles, so as to protect the safety of pedestrians crossing the street

Future research should further develop the comprehensive analysis and modeling of the effects of pedestrian gender, age, telephones, group crossing, and motorist behavior on crossing safety; in addition, what measures can be taken to effectively improve area safety is also a topic worth exploring and studying. Besides, the study of pedestrian characteristics and the impact of pedestrian-vehicle conflicts on traffic operation efficiency to improve single-point traffic efficiency is also an important part of traffic research.

Data Availability

The original datasets in the study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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