Quantitative Analysis of Lane-Based Pedestrian-Vehicle Conflict at a Non-Signalized Marked Crosswalk

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Abstract

Pedestrian-vehicle conflict is a common and dangerous event which occurs in both urban and rural areas in developing countries. Lane-based evaluation of pedestrian-vehicle conflict is still an open research topic in the traffic safety, urban planning, and city government communities. A lane-based approach for evaluating the *post-encroachment time* between pedestrians and vehicles was proposed. This study analyzed the lane-based distribution of pedestrian-vehicle conflict using collected video data which recorded the behaviors of vehicles and pedestrians in a non-signalized marked crosswalk in Wuhan, China, and discussed the effect of waiting time on lane-based pedestrian-vehicle conflict as well as the distribution of pedestrian walking speed under different levels of severity of lane-based pedestrian-vehicle conflict. Experimental results showed that shorter waiting times and smaller waiting areas are very strongly related to lane-based conflict, but that walking speed is not a significant factor in lane-based pedestrian-vehicle conflict.

Keywords: pedestrian-vehicle conflict; post-encroachment time; conflict severity; waiting time; walking speed

1. Introduction

Mixed traffic flows are becoming more common in urban areas all over the world, especially in developing countries such as China. In mixed traffic flow, motor vehicles, non-motorized vehicles (such as bicycles and tricycles), and pedestrians share the same facilities (roads and intersections), and therefore vehicle-vehicle conflicts, bicycle-vehicle conflicts, and pedestrian-vehicle conflicts frequently occur. Many papers in the literature have defined traffic conflict. For example, Zheng *et al.* [1] pointed out that almost all operational definitions of traffic conflict can be grouped into two types: those based on evasive actions, and those based on temporal (and/or spatial) proximity. A representative definition of evasive action-based traffic conflict is "... an event involving two or more road users, in which the action of one user causes the other user to make an evasive maneuver to avoid a collision" [2].

1 According to the literature, a pedestrian-vehicle conflict occurs if the oncoming
2 vehicle has to brake abruptly, if the vehicle has to swerve to avoid colliding with the
3 pedestrian, or if the pedestrian has to take sudden evasive action, such as jumping
4 back to avoid a collision. This definition is based on evasive actions taken either by
5 the driver or by the pedestrian. A representative definition of proximity-based traffic
6 conflict is "... an observable situation in which two or more road users approach each
7 other in space and time to such an extent that there is a risk of collision if their
8 movements remain unchanged" [3]. This means that the closer the road users are to
9 each other, either in time or in space, the nearer they are to a collision. This is more of
10 a conceptual (theoretical) definition, and it is operational because the time and space
11 parameters are quantitative and can be measured by traffic detectors.

12 Pedestrian-vehicle conflicts are hard to formulate because of the unpredictable
13 behaviour of both drivers and pedestrians, which depends on many uncertain factors;
14 this fact has limited research on pedestrian-vehicle conflict in China [4]. Traffic
15 accidents involving pedestrians are a common phenomenon in many cities [5].
16 Pedestrians are among the most vulnerable road users (VRUs) because they lack the
17 physical protection to reduce accident consequences [6]. For example, according to
18 statistics from the Department of Traffic Management of China in 2010, there were
19 65,525 pedestrian fatalities caused by traffic accidents, 24.96% of which involved
20 pedestrians crossing streets [7]. However, pedestrian safety has not been a
21 high-priority topic in China [8]. This high accident percentage reflects the intensive
22 interaction between pedestrians and vehicles. Therefore, it is of vital importance to
23 understand pedestrian street-crossing behavior to improve pedestrian safety [5].

24 A number of published studies have dealt with pedestrian-vehicle conflict, but
25 they were limited to studying the factors influencing conflict, such as personal
26 characteristics, traffic conditions, and environmental factors at crosswalks. From the
27 first perspective, personal characteristics like age, gender, and disability have been
28 studied. For example, Liu and Tung [9] found that elderly pedestrians exposed
29 themselves to higher risk of road crossing than young pedestrians due to their decline
30 in walking ability. Yagil [10] found that men are less aware than women of their
31 conflicts with vehicles when they cross the street. Ariane and Granié [11] explored
32 gender differences in pedestrian rule compliance both at signalized and unsignalized
33 crossroads. From the second perspective, traffic conditions such as traffic volume and
34 vehicle speed have also been studied. For example, Cheng *et al.* [12] proposed that
35 higher vehicle volume might lead to more serious pedestrian-vehicle conflict because
36 pedestrians' waiting time will increase and exceed their tolerance limits; higher
37 vehicle speed resulted in a higher collision probability between pedestrians and
38 vehicles. Cheng also modelled the relationships between pedestrian waiting time and
39 vehicle volume, pedestrian-vehicle conflict time, vehicle speed, traffic delay, and
40 pedestrian volume. Himanen and Kumala [13] analyzed 799 events of
41 pedestrian-vehicle conflict; their results indicated that the most important explanatory

variables included pedestrian distance from the curb, city size, number of pedestrians simultaneously crossing, vehicle speed, and vehicle platoon size. From the third perspective, environmental factors such as city size, signal settings, road width, and lane definition have also been widely studied. Traffic signals are the most important environmental factor because pedestrians and drivers should obey traffic light restrictions at signalized intersections. At a non-signalized marked crosswalk, pedestrians have the right-of-way according to traffic regulations in China, and the vehicles should give the right-of-way to the pedestrians. However, the vehicles usually do not give right-of-way to the pedestrians and drivers are not told when to leave the crosswalk [14], which makes crossing of a non-signalized intersection more complex. Furthermore, pedestrians cross a typical bidirectional four-lane crosswalk to the opposite side at signalized intersections in two stages (one direction, then the other), but four phases (lane by lane) are required to cross to the opposite side at a non-signalized crosswalk. Most of these studies are based on signalized intersections and road sections, and therefore they cannot reflect the complex interpenetration between pedestrians and vehicles and evaluate pedestrian safety at uncontrolled intersections. Therefore, this study investigated lane-based pedestrian-vehicle conflict at a non-signalized crosswalk, which is different from previous related research.

To quantify pedestrian-vehicle conflicts, one of the existing proximity measures should be used. The most popular proximity measures are *time to collision* (TTC) [15] and *post-encroachment time* (PET) [16]. According to the classical definition by Hayward [17], TTC is “the expected time for two road users to collide if they remain at their present speed, direction, and on the same trajectory”. PET is the time between the moment that the first road user leaves the potentially occupied conflict zone and the moment the second road user reaches it. The main difference between PET and TTC is that there is no collision course criterion for PET [18]. Usually, conflicts between pedestrians and vehicles are divided into discrete severity levels according to different thresholds of TTC and PET. For example, Ismail [19] analyzed pedestrian-vehicle conflicts and traffic violations. He used TTC and PET indicators mainly to classify conflicts into four severity levels, from highest to lowest. Higher TTC and PET values indicate lower severity. Malkhamah used vehicle deceleration to divide the severity of conflicts into three different levels: serious, slight, and potential conflict [20]. In addition, for lane-based pedestrian-vehicle conflict, severity is divided into three categories: serious, slight, and potential conflict, according to the PET indicator. Archer [18] indicated that PET is useful for measuring critical events where crossing trajectories for road users are involved. PET makes no speed and direction assumptions, unlike TTC, which makes the PET calculation relatively simple. However, its calculation requires capturing a static conflict point rather than a dynamic point. In cases where a driver performs evasive action, the potential conflict point will be dynamic. Therefore, this paper proposed a lane-based PET (LPET) measure to overcome the limitations of PET by considering the full lane as the

potential conflict zone. Smaller LPET values indicate a higher level of conflict severity between two road users.

This paper makes two contributions. The first is quantifying pedestrian-vehicle conflicts over each lane at a non-signalized marked crosswalk using the proposed safety indicator, LPET. The second contribution is evaluating the influence of pedestrian waiting time on lane-based pedestrian-vehicle conflict as well as exploring the distribution of pedestrian walking speed at each lane and under different levels of conflict severity, which would be helpful for transportation agencies to meet pedestrian's time-cost and comfort needs in crossing streets when they design pedestrian facilities at crosswalks.

2. Materials and Methods

2.1 Study Area and Data.

FIGURE 1: The study area.

A typical non-signalized marked crosswalk area with bidirectional traffic, which is close to a bus station, was chosen as the study area (Figure 1). The size of the marked crosswalk area is approximately $17.4 \text{ m} \times 6 \text{ m}$, which covers four vehicle traffic lanes and two cyclist lanes. The widths of Lane1, Lane2, Lane3, and Lane4 are

4 m, 3.4 m, 3.4 m, and 4 m respectively, while both of the cyclist lanes are 1 meter wide (Figure 2). There is also a 0.6 m-wide area between Lane2 and Lane3 as a physical barrier. The speed limit in this area is 60 km/h.

This study used two cameras (Figure 1) to record the marked crosswalk area for 200 minutes between 10 a.m. and 2 p.m. on a weekday. Camera #1 was placed on the 22nd floor (approximately 80 meters high) of an office building, and Camera #2 was placed on the roof (approximately 30 meters high) of a residential building. Camera #1 helped to extract vehicle positions at all times during the conflict, while pedestrians' positional measurement and velocity could be obtained from Camera #2. The researchers decoded both collected videos into frames and synchronized them manually. Because the frame rates of these videos were the same (i.e., 25 fps), the synchronized time error between these videos was approximately 0.04 seconds ($=1 / (25-1)$). Based on the collected videos, this study identified the vehicles and pedestrians in these videos by manual means. The average walking speed of the pedestrians in this area was 1.3 m/s while the average speed of vehicles when approaching the crosswalk is about 30 km/h. In the collected videos, there were 5749 cars (61.38%), 617 buses (6.59%), 1384 motorcycles (14.78%), 186 bicycles (1.99%), 1262 pedestrians (13.46%), and 169 other types of vehicles (ambulance, police car, gas tanker, etc.) (1.80%). Their locations were recorded according to the time tags in the video frames. Because of the complexity of group behavior in the crosswalk area, this study selected 555 individual pedestrians who crossed this area in directions D3 and D4 (Figure 2). Other pedestrians who crossed in groups were excluded from the study data set. D1 and D2 represent the main traffic flow, while D5 and D6 represent the right-turn traffic flow.

FIGURE 2: Directions of traffic flow.

2.2 Estimation of LPET between pedestrians and vehicles.

At a non-signalized crosswalk, pedestrians have to cross lane by lane without guidance from any special signaling facilities to arrive at the opposite side of the road. Theoretically, for each pedestrian during his/her crossing, the conflict zone is a “common area used by road-users/vehicles approaching from different trajectories”

[18]. In this zone, the pedestrians are exposed to the risk of oncoming vehicles.

Archer pointed out that PET has good performance in analyzing conflicts during pedestrian street-crossing behavior. However, a fixed conflict point of collision is required to measure PET, rather than a dynamic conflict point [18]. In case where a driver takes evasive action, the conflict point will be dynamic. As illustrated in Figure 3-(a), if the driver performs an evasive action while driving the vehicle, the location of the conflict zone as well as the conflict point varies from time t_0 to time t_N , and

t_m , t_n , t_p are three time stamps during a vehicle's evasive action.

FIGURE 3: The difference between (a) PET and (b) LPET. (The mark “X” stands for the potential conflict point and the red area is the conflict area.)

To overcome the limitations of PET, the full lane was considered as the conflict zone, meaning that the conflict point was static for each conflict between one pedestrian and one vehicle. Thus, as illustrated in Figure 3-(b), even if the driver performs an evasive action within the lane while driving the vehicle, the location of the conflict zone as well as the conflict point is static from time t_0 to time t_N .

Lane-based PET (LPET) was proposed to measure the severity of lane-based pedestrian-vehicle conflict.

FIGURE 4: Calculation of Lane-based PET. (The mark “X” stands for the potential conflict point and the red area is the conflict area.)

For each pedestrian $P = 1, 2, 3, \dots, N$, the time of his/her approach to the conflict zone was recorded as T_0 and the time of his/her leaving the conflict zone as T_1 (as shown in Figure 4-(a), where the pedestrian is leaving the conflict zone).

Therefore, the time for a pedestrian to cross the conflict zone can be calculated as:

$$\Delta T_p = T_1 - T_0. \quad (1)$$

For each vehicle, the time of its approach to the conflict zone was recorded as T_2 (as illustrated in Figure 4-(b), where the vehicle is just approaching the conflict zone). Therefore, when a pedestrian approached the conflict zone, the time for the vehicle to reach the conflict zone could be calculated as:

$$\Delta T_v = T_2 - T_0. \quad (2)$$

Then LPET could be calculated as:

$$LPET = \Delta T_v - \Delta T_p = T_2 - T_1. \quad (3)$$

LPET is the time difference between when the pedestrian leaves the conflict zone and when the vehicle approaches the conflict zone.

The LPET value can be negative; if a vehicle passes the conflict zone before the pedestrian has finished crossing the lane, ΔT_p will be greater than ΔT_v . In this situation, the pedestrian has passed the vehicle, but has not yet finished crossing the lane.

To identify traffic conflict severity, threshold values should be established. These values vary across studies [1]. In [21], thresholds values varied from 1.0 s to 5.0 s. Peesapati *et al.* [22] tested different thresholds varying from 1.0 s to 10 s and selected 1.0 s as the one that produced the best results. This variation of threshold values may be caused by the heterogeneity imposed by type of road, type of vehicle, involved road users, and weather on traffic conflicts [23].

In this research, lane-based PET threshold values were 1.0 s and 5.0 s, and descriptions of the different severity levels of lane-based pedestrian-vehicle conflict are shown in Table 1. The selection of these values can be explained by the following considerations. Archer [18] pointed out that the PET maximum threshold is set to a value of 1.5 seconds, which is slightly higher than the threshold value suggested by Hydén [24] to distinguish between severe and non-severe PETs because he thought that a slightly higher maximum threshold value would be appropriate to obtain sufficient data for safety indicator comparison purposes, given the investigative nature of the study. In the selected study area, the width of the coming vehicles varied from 1.6 m to 2.8 m, and therefore the width of the LPET conflict zone was approximately 0.6 m (3.4 – 2.8) to 2.4 m (4 – 1.6) wider than the width of the vehicles. The average walking speed of the pedestrians in this area was 1.3 m/s, meaning that pedestrians needed to take 0.46 s to 1.85 s more to pass through the LPET conflict zone than they needed for the PET conflict zone. In this case, the PET maximum threshold should be less than 1.5 seconds. In this context, it was determined as $1.5 - 0.46 \approx 1$ second. For Camera #1 (Figure 1), the width of the coverage area was approximately 160 m, with a distance to both crosswalks of about 80 meters. Because the speed limit for vehicles in this area is 60 km/h (about 16.67 m/s), a vehicle will take nearly 5 (80 / 16.67) seconds to approach the crosswalk. In this situation, if the pedestrian finishes crossing the street just when the vehicle appears on the scene, he/she will surely cross the street safely without any danger. Therefore, pedestrian-vehicle conflicts with LPET values larger than 5 seconds can be thought of as potential conflicts.

TABLE 1: Description for different severity of pedestrian-vehicle conflict.

LPET Values (second)	Severity of Conflict	Description
$LPET \leq 1$	Serious Conflict	In this situation, the pedestrian rushed to cross the lane in the presence of a coming vehicle, and the vehicle is so <i>near</i> to the pedestrian.
$1 < LPET \leq 5$	Slight Conflict	In this situation, the pedestrian crossed the street in the presence of a coming vehicle, and the vehicle is <i>far</i> from the pedestrian.
$LPET > 5$	Potential Conflict	In this situation, the pedestrian crossed the street in the presence of a coming vehicle, and the vehicle is <i>far enough</i> from the

		pedestrian.
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3. Statistical results

3.1 Number of conflicts of different levels of severity over two directions and four lanes based on LPET data.

For 555 selected individual pedestrians, there were 2220 (555×4) crossings in total. 1153 crossings occurred in the absence of vehicles and therefore did not result in a conflict situation. The other 1067 crossings were evaluated based on LPET thresholds, including 207 serious conflicts, 657 slight conflicts, and 203 potential conflicts. These LPET values were calculated according to Eqs. (3).

At least 87 pedestrians experienced conflict four times while crossing. Details about conflict numbers in different lanes by crossing direction are summarized in Table 2.

TABLE 2: Conflict number of different levels of severity over two directions.

Direction	Lane	Serious Conflict	Slight Conflict	Potential Conflict	Total
D3	Lane1	3	59	16	78
	Lane2	49	89	6	144
	Lane3	11	97	17	125
	Lane4	51	75	17	143
	Subtotal	114	320	56	490
D4	Lane4	19	95	25	139
	Lane3	45	79	21	145
	Lane2	3	110	68	181
	Lane1	26	53	33	112
	Subtotal	93	337	147	577

In general, conflicts occurred most frequently in Lane#2 (144) and Lane#4 (143) for pedestrians in D3, while for pedestrians in D4, conflicts occurred most frequently in Lane#2 (181) and Lane#3 (145). Slight conflicts were the most frequently occurring conflicts for both D3 (320) and D4 (337). Moreover, D4 had many more potential conflicts (147) than D3 (56). It is clear that conflicts were not distributed evenly over the four lanes, and further investigations should be conducted to explore these differences.

3.2 Percentage of serious conflicts over the four lanes.

The percentage of conflict occurrence, P_{conflict} is calculated as:

$$P_{conflict} = \frac{N_{slight} + N_{serious}}{N_{crossing}} P_{conflict} = \frac{N_{slight} + N_{serious}}{N_{crossing}}, \quad (4)$$

where N_{slight} is the number of slight conflicts, $N_{serious}$ is the number of serious conflicts, and $N_{crossing}$ is the total number of pedestrian crossings.

Accordingly, the percentage of serious conflict occurrence, $P_{serious}$, can be calculated as:

$$P_{serious} = \frac{N_{serious}}{N_{slight} + N_{serious}} P_{serious} = \frac{N_{serious}}{N_{serious} + N_{slight}}. \quad (5)$$

$P_{serious}$ is an important parameter in conflict analysis because it represents the percentage of potentially dangerous pedestrian-vehicle accidents. In this research, $P_{serious}$ was 26.27% (D3) and 21.63% (D4) respectively, and for all pedestrians, $P_{serious}$ was 23.96%.

FIGURE 5: Serious conflicts percentage over lanes.

Table 2 illustrates that the number of serious conflicts (126) in D4 was higher than the number of serious conflicts (81) in D3. Investigation of pedestrian-vehicle conflicts by lane showed that the far lanes (Lane#2 and Lane#4 for D3, Lane#1 and Lane#3 for D4) had much higher numbers of conflicts than the near lanes (Lane#1 and Lane#3 for D3, Lane#2 and Lane#4 for D4), as shown in Figure 5.

Both pedestrians and drivers caused serious conflicts in far lanes. Before

approaching the median, pedestrians found themselves in conflict in the far lane when they crossed the near lane and rushed to finish crossing the far lane because the remaining distance to the median was smaller than the distance from the starting point to the far lane (Figure 2). According to traffic regulations, the speed limit for vehicles driving in Lane#2 and Lane#3 is higher than the speed limit in Lane#1 and Lane#4. Once a car is stopped or driving in Lane#1 or Lane#4, it partially blocks the visibility of drivers in Lane#2 and Lane#3 (Figure 6-(a)). Therefore, drivers maintain the same high speed because they do not anticipate pedestrians. Pedestrians rush to approach the median despite the high danger in that lane. After crossing the median, pedestrians tended to have more unsafe crossing on the far lanes. 40.48% serious conflicts were recorded in the far lane (Lane #4) for pedestrians in D3, and 32.91% serious conflicts were recorded in the far lane (Lane #1) for pedestrians in D4. Zhuang et al. [25] suggested that pedestrians wish to finish the crossing quickly at the far lanes because pedestrians expect less danger at the far lanes as the distance to cover is smaller.

Crossing without watching for oncoming vehicles is one aspect of unsafe pedestrian crossing behavior [10]. 4.84% of serious conflicts happened in the first lane (Lane #1) for pedestrians in D3, and 16.67% of serious conflicts happened in the first lane (Lane #4) for pedestrians in D4. These serious conflicts in near lanes occurred when the pedestrian entered the crossing immediately before a vehicle approached (Figure 6(b)); the driver decelerated, and the pedestrian walked faster or started running. This is one of the most dangerous conflict situations because the driver does not anticipate the presence of pedestrians. For potential, slight and serious conflicts, the average speeds of approaching vehicles were 29.33 km/h (SD=8.65), 31.97 km/h (SD=9.42) and 31.63 km/h (SD=10.84) respectively. For all the vehicles when approaching the conflict area (mainly around the crosswalk), the maximum speed was 54.45 km/h and the minimum speed was 6.18 km/h.

FIGURE 6: Serious conflicts situations.

4. Discussion

Few studies have been carried out dealing with pedestrian walking speed and waiting time in the context of pedestrian-vehicle conflict at non-signalized crosswalks. Pedestrian waiting time reflects pedestrian delay at intersections. Traditionally, urban network management has paid more attention to minimizing vehicle delays and little attention to delays encountered by pedestrians [26]. An in-depth understanding of the influence of waiting time on pedestrian-vehicle conflict would alert designers, planners, and managers to pedestrians' needs, thus making urban areas more pedestrian-friendly [26]. Moreover, the distribution of road users' speeds is an important input for many traffic flow models, for example, many microscopic simulation models obtain the walking speeds of individual pedestrians from a walking speed distribution [27]. This study has discussed the influence of waiting time on lane-based pedestrian-vehicle conflict and distribution of pedestrian walking speed under different levels of severity of lane-based pedestrian-vehicle conflict.

4.1 Influence of waiting time on lane-based pedestrian-vehicle conflict.

Waiting time is the time difference between the pedestrian's arrival time and the pedestrian's departure time at the same crossing area. Generally, pedestrians preferred crossing actively rather than waiting passively [25]. However, waiting time can significantly deter people from walking or can lead to unsafe crossing behavior [26].

The average waiting time of individual pedestrians was recorded over four phased areas during pedestrian crossings:

(1) Pedestrian waiting at the approach lane area (which could be the curb or the cyclist lane), (2) Pedestrian waiting between Lane 1 and Lane 2, (3) Pedestrian waiting at the median area, (4) Pedestrian waiting between Lane 3 and Lane 4.

FIGURE 7: Pedestrian's average waiting time at different lane areas (unit: second).

Figure 7 shows that the waiting time at the approach lane area was higher in D4 (5.03s) than at the same lane area in D3 (4.34s) because the traffic volume coming from D2 was much higher than that from D1. Vehicles move in platoons, and drivers in groups are less willing to give way to pedestrians. In contrast, the waiting time at the median area for pedestrians coming from D4 (3.31s) who wanted to cross through D1 was less than the waiting time at the median area for pedestrians coming from D3 (5.16s) who wanted to cross through D2. For both directions, when pedestrians arrived at the far lane area, they waited only for a short time or not at all before starting to cross; perhaps this is the main reason for the high numbers of conflicts in the far lanes.

TABLE 3: The numbers of serious, slight and potential pedestrian-vehicle conflict by the waiting time.

Waiting Time (s)	[0,3]	(3,30]	(30,+∞)
Serious Conflict	194	9	4
Slight Conflict	534	116	7
Potential Conflict	153	47	3
Total	881	172	14

On the basis of data from Table 3, shorter waiting time (less than 3 seconds) caused 881 conflicts. The number of conflicts decreased as waiting time increased. It is worth noting that the number of serious conflicts decreased significantly (from 194 to 9) when the waiting time went from 3 seconds to 30 seconds. There were also four pedestrians who crossed in very risky situations after waiting for more than 30 seconds. Similar results were suggested in [28] [29].

4.2 Distribution of pedestrian walking speed under different levels of severity of lane-based pedestrian-vehicle conflict.

Pedestrian walking speed is a fundamental property of pedestrian flow which can be used in a wide range of applications. Prior knowledge of walking speed is required in many types of transportation studies such as: developing pedestrian simulation models, estimating facility level of service, and designing pedestrian signals [21]. The selected non-signalized crosswalk in this study is located on a wide bidirectional four-lane street where pedestrians were expected to cross lane by lane. The walking speed was calculated by dividing the length of each crossing by the crossing time. The average walking speed of individual pedestrians was recorded in each lane.

TABLE 4: Pedestrian walking speed (the 15th, 50th and 85th percentile speeds measured in m/s).

Direction	Conflict Severity	Lane1			Lane2			Lane3			Lane4		
		15th	50th	85th	15th	50 th	85th	15th	50th	85th	15th	50th	85th
D3	Serious	0.93	1.22	1.27	1.03	1.21	1.51	0.90	1.09	1.13	1.08	1.34	1.50

	Conflict												
	Slight Conflict	1.02	1.38	1.62	0.98	1.24	1.63	0.78	1.16	1.64	1.06	1.30	1.55
	Potential Conflict	1.12	1.39	1.55	1.01	1.09	1.48	0.83	1.16	1.70	1.15	1.53	1.83
D4	Serious Conflict	1.10	1.43	1.81	0.86	1.11	1.13	0.96	1.16	1.48	0.76	1.37	1.57
	Slight Conflict	1.16	1.37	1.59	1.06	1.41	1.65	0.97	1.20	1.42	0.98	1.21	1.49
	Potential Conflict	1.21	1.43	1.61	1.01	1.34	1.59	0.90	1.12	1.38	0.90	1.15	1.46

Table 4 shows the 15th, 50th, and 85th percentiles of pedestrian crossing speed for each lane under different levels of conflict severity. Percentile speeds (15th, 50th, and 85th) were calculated, which can be the useful references in determination of local parameters when designing pedestrian facilities because the direct use of foreign design codes or parameters for pedestrian facilities has been a concern in developing countries [30]. The 15th percentile of pedestrian walking speed indicates that 85% of pedestrians walk more quickly than this speed. In contrast, the 85th percentile of walking speed indicates that 15% of pedestrians walk more slowly than this speed. The 50th-percentile walking speed represents an equal probability of being followed or overtaken [31].

TABLE 5: Chi-square test results on pedestrian walking speed.

Factors	Chi-Square(χ^2)	Degrees of freedom	Significance $P = 0.95$ $\alpha = 0.05$
Lanes (Lane1, Lane2, Lane3, Lane4)	69.672	6	Yes
Crossing Stages (1 st Stage, 2 nd Stage)	31.186	2	Yes
Crossing directions (D3, D4)	2.575	2	No
Severity of Conflicts (Serious, Slight, Potential)	3.143	4	No
Lanes (Near Lane, Far Lane)	26.586	2	Yes

The Chi-squared test was used to evaluate the significance of the impact of contributing factors on pedestrian walking speed. The results showed that three out of five variables were found to have a significant association with pedestrian crossing speed (Table 5). There was a strong relationship between pedestrian walking speed and lanes. Pedestrian walking speeds in Lane#1 (mean=1.33 m/s) and Lane#2 (mean=1.27

m/s) were higher than in Lane#3 (mean=1.18 m/s) and Lane#4 (mean=1.24 m/s). Pedestrians were more likely to walk faster in *far lanes* (mean=1.28 m/s) than in *near lanes* (mean=1.23 m/s). Moreover, there was a significant difference in terms of walking speed and *crossing stage*. This finding indicates that pedestrians walk faster after finishing one stage of crossing. The mean walking speed in the first stage (before the median) was 1.21 m/s, while that in the second stage (after the median) was 1.30 m/s. This study also found that the *severity of conflict* and the *direction of crossing* were non-contributing factors influencing pedestrians' walking speed.

4.3 Reliability and Validity of LPET

According to [32] [33], reliability refers to the accuracy of the method used to measure the indicator. In our study regarding lane-based pedestrian-vehicle conflict, reliability refers to the accuracy to measure the severity of conflict using LPET by video analysis. Unlike the traditionally observer-based approach, video-recording can be considered as more objective ones, and can provide repeated assessment [34]. When calculating LPET, motion information (e.g. speed, distance) of the road users are unnecessary and only time stamps are required. And in the context of LPET, the whole lane is considered as the conflict zone, making the conflict point static for each conflict between one pedestrian and one vehicle. Thus LPET has the property that it can be measured "with the same accuracy and objectivity regardless to where, in what conditions and by whom the measurements are performed" [32].

Several issues were raised in validating any indicator in TCT [1] [35]. The traditional way to validate an indicator is to correlate the conflict results with historical accident data for those sites, or compare the conflict rates to traditional crash prediction models [36]. Historical accident data can be useful for validation when the geometrical features of the study sites does not change, however, some major changes (e.g. reconfigured crosswalk) have occurred during the year period in which accident data was recorded in our site, as a consequence, historical data cannot be used to validate LPET. Besides, this historical accident data didn't contain any lane information, so it is hard to compare LPET results on different lanes with the historical data. In future, recording more detailed information (e.g. lanes) would be helpful. Hence, establishing the validity of the indicator requires numerous large-scale studies performed in various conditions and the correlations found have to be supported by a theory which provides clear logical and causal connection between the indicator and the quality it is supposed to represent [37].

5. Conclusions

This study has demonstrated the feasibility and effectiveness of considering the evasive actions of drivers in evaluating lane-based pedestrian-vehicle conflicts at a

non-signalized marked crosswalk in Wuhan City, China. A novel indicator, lane-based PET (LPET), was proposed to classify lane-based pedestrian-vehicle conflict into three different levels: serious, slight, and potential conflicts, based on LPET threshold values. Based on the above evaluation, several conclusions were drawn as follows:

i) The severity of lane-based pedestrian-vehicle conflict over each lane was evaluated. Results showed that conflicts were not distributed evenly over the four lanes. For each traffic flow direction (D3, D4) in the study site, the far lanes recorded a higher percentage of serious conflicts than the near lanes, and slight conflicts were the most frequently occurring conflicts for both directions.

ii) The relationship between pedestrian waiting time and pedestrian-vehicle conflicts was also investigated. Analytical results showed that shorter waiting time (less than 3 seconds) caused 881 conflict situations between pedestrians and vehicles. As pedestrian waiting time went from 3 seconds to 30 seconds, serious conflicts decreased significantly (from 194 to 9). When pedestrian waiting time went beyond 30 seconds, pedestrians crossed in very risky situations.

iii) This study also explored the distribution of pedestrian walking speed under different levels of severity of lane-based pedestrian-vehicle conflict. It was found that pedestrian walking speed was not affected by the severity of pedestrian-vehicle conflicts or the direction of crossing; however, it was always higher in the far lanes and in the second stage of crossing. The authors believe that pedestrian walking speed data need to be further analyzed to develop a better understanding of the factors influencing pedestrian walking speed.

The findings above need to be interpreted in an objective way and should be cautious in drawing conclusions for policy decisions because these findings may vary in different “road crossing cultures”. Due to the difficulty in exploring pedestrians’ psychological aspect from video data, a different approach (*e.g.* using questionnaires or interviews, studying pedestrian behavior in simulation environment) should be adopted in future work to explore the cognitive process of pedestrians’ road crossing behaviors in different “road crossing cultures”. Moreover, using more than one indicator can improve our work in future by overcoming the limitations of individual conflict indicator.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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