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Exploring Cyclist Flow Patterns at Signalized Crossing: Perspective of Cyclist-pedestrian Conflict Analysis

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Abstract: This research seeks to explore the behavioral patterns related to cyclist-pedestrian conflicts against the presence of dedicated bike lanes, so as to provide empirical and quantitative insights for the current design guidelines. Upon the consideration of data collection, this research chooses the conflicts occurring at signalized crossings, where higher frequencies of conflicts can be expected due to various types of interactions among dense crossing flows accumulated during the red phase. Video streams were filmed over the crossings around National Taiwan University in Taipei, Taiwan. Trajectories of individual cyclists and pedestrian flows were abstracted to identify the aggregate behavioral pattern. Among all the conflicts, cyclist-pedestrian head-on conflict in opposite directions and cyclist-pedestrian rear-end conflict in the same direction are the most. The Poisson regression model was developed, and it shows that conflicts tend to appear in the first 20s of the signal cycle, and they increase as pedestrian flows increase.

Keywords: Cyclist-pedestrian Conflict, Dedicated Bike Lane, Pedestrian Behavior, Cyclist Behavior, Signalized Crossing, Poisson Regression Model

1. INTRODUCTION

To develop safer and friendlier environments for cycling and walking has received increasing attention along the trend to foster sustainable transportation, particularly from the perspective of transforming street design. The growing popularity of cycling in recent years also induces the argument over the right of way for cyclists: sharing lanes (slow lanes or motorcycle lanes) with other motorized vehicles exposes cyclists to the risk and pressure of interacting with those faster-moving vehicles, while riding on sidewalks, on the other hand, leads to potential conflicts between cyclists and pedestrians. Building dedicated bike lanes seem to be an effective way to separate cyclists from other traffic flows in light of the described development trend and safety concerns. Hence, many cities have deployed or planned dedicated bike lanes either aside driveways or on sidewalks, aiming to establish well-connected cycling routes or even networks and thereby encouraging the use of the greener mobility.

However, because of limited space, to allocate dedicated right of way to cyclists is more or less opposed by other road users. In addition, the effectiveness of dedicated bike lanes is questioned or even criticized in terms of their utilization rates. Especially, for those built on sidewalks, it is frequently observed that some cyclists still ride on the space of pedestrian walkways, even though dedicated bike lanes are available right aside; on the contrary, there are also the cases that pedestrians walk on dedicated bike lanes. As cyclists and pedestrian are still significantly different from each other in terms of their movement characteristics, conflicts or even collisions between cyclists and pedestrians seem to remain, so do the arguments over building/expanding dedicated bike lanes. Cyclists and pedestrians are both vulnerable, compared with those who drive/ride motorized vehicles. Nevertheless, such cyclist-pedestrian conflicts are comparatively minor in general, and therefore few records of them are made, which presents one of the major challenging aspects for relevant research to better comprehend the behavior of cyclists and pedestrians over using/competing for the right of way. Likewise, current design guidelines for dedicated bike lanes are primarily based on conceptual principles but lack theoretical understanding and explanation from the perspectives of road users.

This research seeks to explore the behavioral patterns related to cyclist-pedestrian conflicts against the presence of dedicated bike lanes, so as to provide both empirical and quantitative insights for the current design guidelines. Upon the consideration of data collection, this research chooses to focus on the cyclist-pedestrian conflicts occurring at signalized crossings, where higher frequencies of conflicts can be expected due to various types of interactions between dense crossing flows accumulated during the red phase. The derived research findings may feedback to the current design guidelines and following policymaking. Ultimately, we are seeking to extend the relevant insights to the problem of flow separation on sidewalks and provide the capability to develop a better urban design for cycling traffic management.

2. METHODOLOGY

2.1 Data Collection

Pedestrian and cyclist crossing data were collected from three signalized crossings (as shown in Figure 1) around the campus of National Taiwan University in Taipei, Taiwan. Estimated according to the General Affairs Office of the university, there are 80% of students and employees own a bike; in other words, there are about 30 thousand bikes in the campus. Heavy cyclist and pedestrian traffic can be observed at the selected signalized crossings, as college students can be one of the major cyclist groups (as illustrated in Figure 2). Among some of these crossings, the average crossing traffic can attain nearly 30 bikes and more than 50 pedestrians per cycle (45-65 seconds) during the peak hours, which can result in a great degree of flow weaving and probably the consequence of collision.

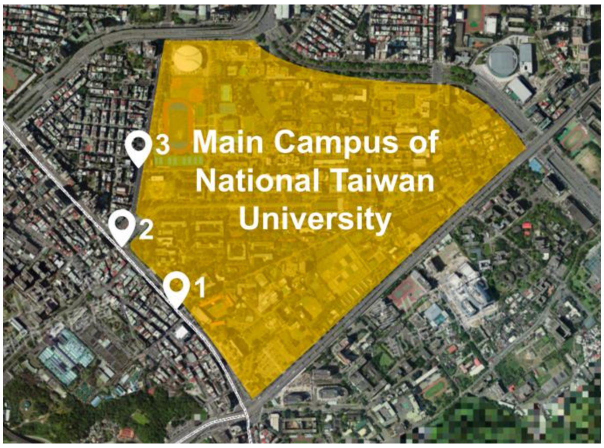

Figure 1. Three selected signalized crossings around National Taiwan University.

Figure 2. Pedestrian and cyclist traffic at Crossing 2 during peak hours.

In this research, pedestrian and cyclist crossing trajectories were recorded using a drone (Mavic Pro, SZ DJI Technology Co., Ltd.) set up right above the crossings, which can avoid influencing pedestrian and cyclist crossing behavior. The recorded video streams provide the advantage of allowing every crossing and conflict event to be measured and the motion of each road user to be accurately identified. Moreover, the video streams can be kept permanently, which can be accessed for more in-depth analysis or if additional information is to be further abstracted. The frame rate is 30 frames per second in all recorded video streams. The crossing data were collected between April 2018 and June 2018, and all collected during similar weather conditions (not raining) with similar outdoor temperatures (between 22℃ and 30℃). With dry roads and dry crossings, we can focus on the characteristics of road users and crossings. For each selected crossing, pedestrian and cyclist movements were recorded for approximately 30 minutes during one morning peak period (8:00 am to 9:00 am), one evening peak period (5:00 pm to 6:00 pm), and one off-peak period (10:00 am to 12:00 pm or 3:00 pm to 5:00 pm). All data were collected during weekdays. Although there are still people riding bicycles to the campus on weekends, for studying, club activities, or hiking, the amount of these people is small and without regularity. It is difficult to grasp the time suitable for data collection. The data collected in this study on weekdays is sufficient to show the crossing behavior when the crossing flow is different, so only the weekdays are selected for data collection.

The collected data can be divided into two major categories, characteristics of crossing and characteristics of conflict. The characteristics of crossing include width, length, signal timing, bus platform or not, and connected with a bike lane or not. These data can be directly collected by observation and simple on-site measurement. The characteristics of conflict include the times and locations that conflicts happen, the speeds of conflict participants, the flow and the associated density when the conflict happens, and the conflict indicator TTC (Time-to-collision). These data can be abstracted after filming video streams.

This study selects three crossings for analysis, which are illustrated in Figure 1. Crossing 1 is the north side crossing of the two-way signal-controlled intersection at Roosevelt Road as shown in Figure 3b (the crossing circled in Figure 3b), and crosses Roosevelt Road, which is a wide road with four lanes including a dedicated bus lane of traffic in each direction. The total length of Crossing 1 is 32 meters. The side for pedestrian crossing has a width of 5 meters, and the side for bicycle crossing has a width of 2 meters, respectively. The pedestrian signal varies across different time periods. The green interval is 60 seconds in a total cycle of 200 seconds in morning peaks; the green interval is 40 seconds in a total cycle of 150 seconds in off peaks; the green interval is 50 seconds in a total cycle of 200 seconds in evening peaks. This provides sufficient time to enable most pedestrians and cyclists to cross the road safely. However, the waiting time for pedestrians and cyclists seems too long. Crossing 2 is the south side crossing of the four-way signal-controlled intersection between Roosevelt Road and Xinsheng South Road as shown in Figure 4b (the crossing circled in Figure 4b), and crosses Roosevelt Road, which is a busy and wide road with four lanes for the southbound traffic and five lanes for the northbound traffic. The total length of Crossing 2 is 30 meters. The side for pedestrian crossing has a width of 3 meters, and the side for bicycle crossing has a width of 2 meters, respectively. The pedestrian signal varies across different time periods. The green interval is 65 seconds in a total cycle of 185 seconds in morning peaks; the green interval is 44 seconds in a total cycle of 145 seconds in off peaks; the green interval is 56 seconds in a total cycle of 185 seconds in evening peaks. Crossing 2 has the same problem as Crossing 1, the red intervals seem too long. We observe that most of the cyclists finish crossing in the first 20 seconds of green intervals, and most of the pedestrians finish crossing within 30 to 40 seconds, which indicates that the total cycle length can be shorten. It will be safer with red intervals under 100 seconds. Crossing 3 is the south side crossing of signal-controlled T road at Xinsheng South Road as shown in

Figure 5b (the crossing circled in Figure 5b), and crosses Xinsheng South Road, which has three lanes of traffic in each direction. The total length of Crossing 3 is 22 meters. The side for pedestrian crossing has a width of 3 meters, and the side for bicycle crossing has a width of 1.4 meters, respectively. The green interval is 45 seconds in a total cycle of 205 seconds in morning peaks; the green interval is 35 seconds in a total cycle of 150 seconds in off peaks; the green interval is 40 seconds in a total cycle of 200 seconds in evening peaks. Although the green intervals are sufficient for pedestrians to cross the entire crossing, the waiting time of Crossing 3 is too long. It is the longest among the three selected crossings, and Crossing 3 is also the one that has captured people crossing during red intervals in the filmed video of our research. The dangerous behavior of one man resulted in herd behavior which influenced other pedestrians and cyclists to follow him crossing the road. Shorten the red intervals can reduce the occurrence of such dangerous situation.

The characteristics of crossing are listed in Table 1. Crossing 1 has the widest pedestrian crossing with 5 meters; Crossing 3 has the smallest bicycle crossing width of 1.4 meters. The width of bicycle lanes should be at least 1.5 meters for single direction, and above 2.5 meters for two directions. It is not appropriate to design bicycle crossings with 1.4 meters or 2 meters since there are heavy cyclists flow in peak hours.

The surroundings of three crossings are illustrated in Figure 6. While Crossing 1 has bus platform as a mid-block, both Crossing 2 and Crossing 3 have no mid-block. Crossing 1 and Crossing 2 have no connected bike lane while Crossing 3 is connecting with dedicated bike lanes on both side. Crossing 1 and Crossing 2 have bike share system surrounded. There are not only dedicated bus lane, but also two Metro exits connecting with Crossing 1. Crossing 2 is

Table 1. The characteristics of crossings

		Length (m)	Width (m)		Signal timing (s)			Bus platform	Bike lane
			Pedestrian crossing	Bycicle crossing	Green interval	Red interval	Total		
Crossing 1	Morning peaks	32	5	2	60	140	200	Yes	No
	Off peaks				40	110	150		
	Evening peaks				50	150	200		
Crossing 2	Morning peaks	30	3	2	65	120	185	No	No
	Off peaks				44	101	145		
	Evening peaks				56	129	185		
Crossing 3	Morning peaks	22	3	1.4	45	160	205	No	Yes
	Off peaks				35	115	150		
	Evening peaks				40	160	200		

connected to the main gate of the campus as shown in Figure 4b (the white arrow), while Crossing 1 and Crossing 3 are connected to a side gate of the campus as shown in Figure 3(b) and Figure 5(b) (the white circle). There are dormitories, another school campus, night markets, stores, and many restaurants on the other side of Crossing 1 and Crossing 2. Hence, the pedestrian and cyclist activites are higher than Crossing 3 while the other side of Crossing 3 is mainly residential area.

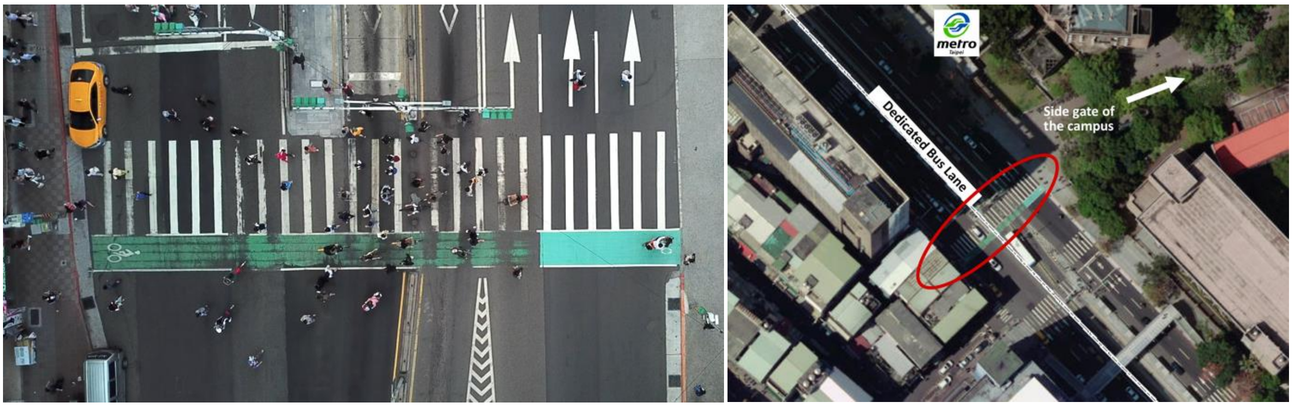

Figure 3. (a) The view of drone of Crossing 1; (b) The complete view of the intersection where Crossing 1 locates.(Source: Department of Urban Development, Taipei City Government)

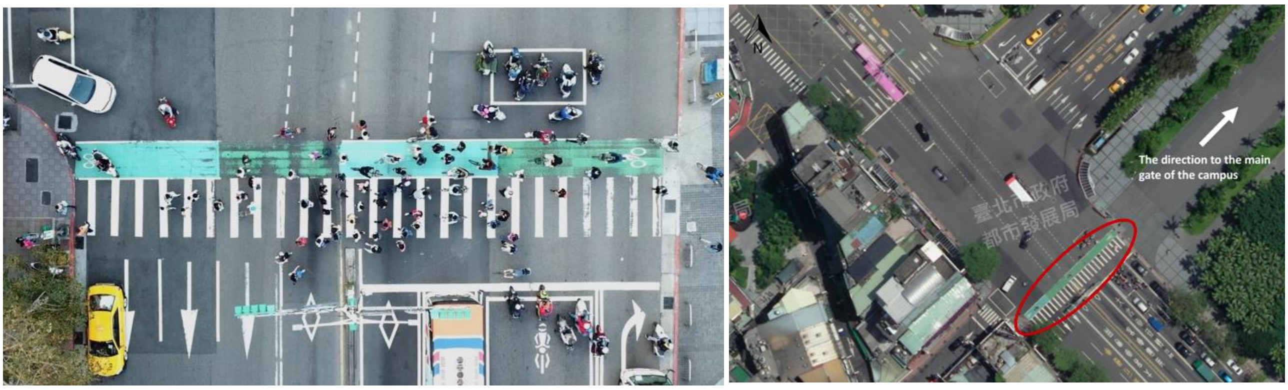

Figure 4. (a) The view of drone of Crossing 2; (b) The complete view of the intersection where Crossing 2 locates.(Source: Department of Urban Development, Taipei City Government)

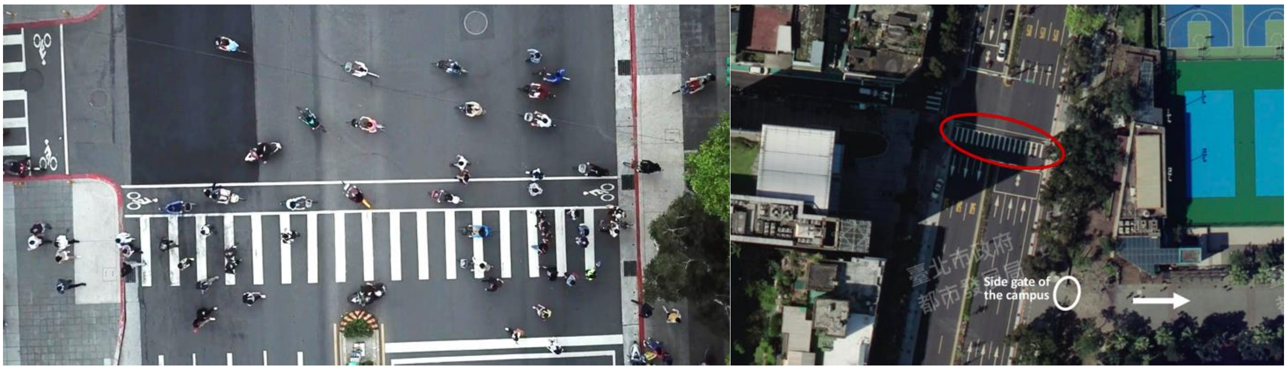

Figure 5. (a) The view of drone of Crossing 3; (b) The complete view of the intersection where Crossing 3 locates.(Source: Department of Urban Development, Taipei City Government**)**

To abstract the characteristics of conflict, we first obtained two kinds of data manually,speed and location. We divided the crossings into three zones (east, median, and west) as shown in Figure 7. The three zones were selected using the density variation caused by the pedestrian crossing behavior and then separated using the curbs and markings of roads.

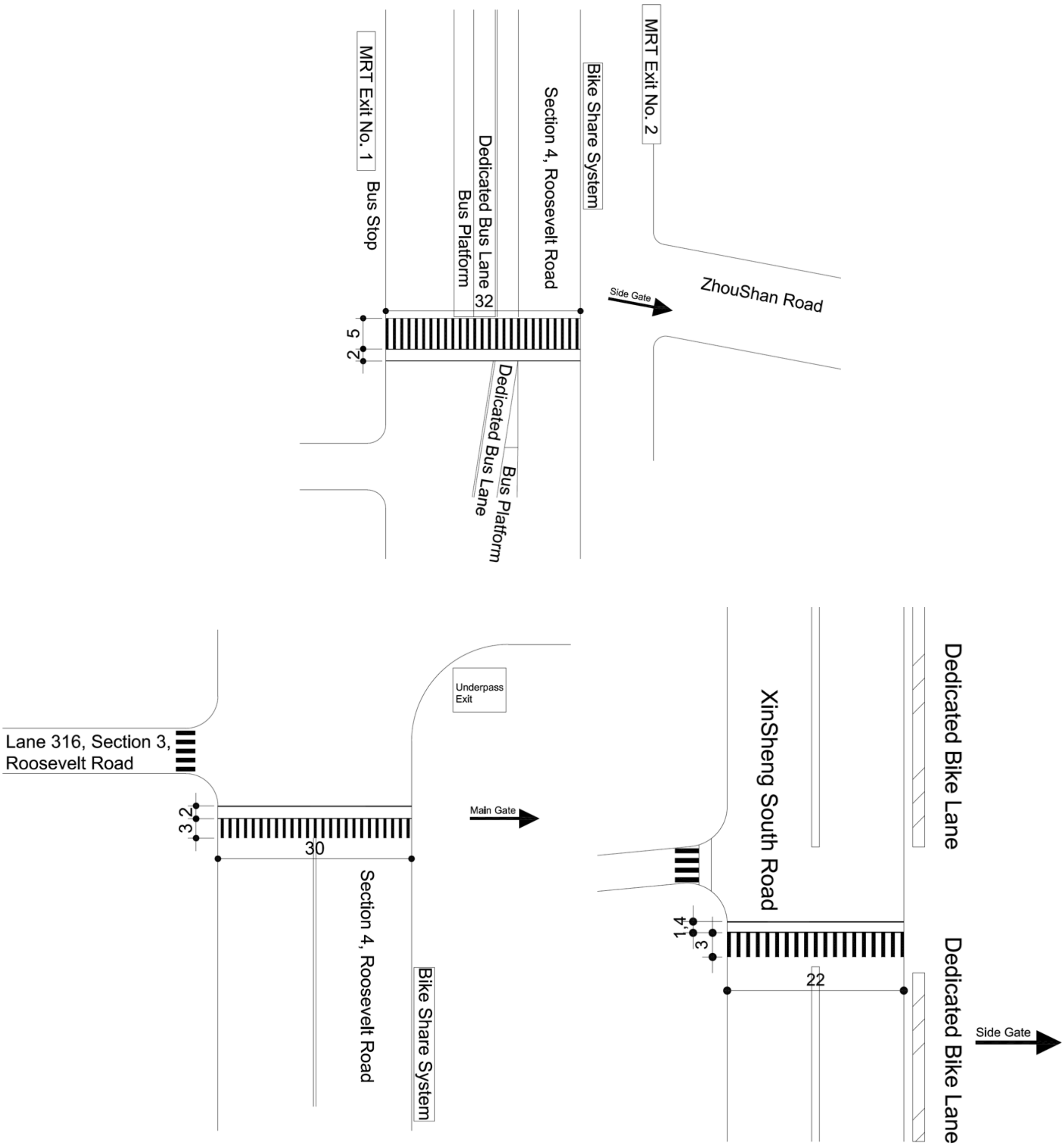

Figure 6. Illustration of the study intersection. (a) Crossing 1; (b) Crossing 2; (c) Crossing 3.

Crossing 1 contains two lanes on both east zone and west zone, 7 meters and 8 meters in width respectively; the median zone has four lanes inculding two dedicated bus lanes plus the bus platform, which is 17 meters in width. The east zone of Crossing 2 contains a width of two lanes, approximately 7.5 meters; the median zone contains four lanes and has a width of

13.5 meters; the west zone has three lanes and 9 meters in width. Crossing 3 has two lanes on both east zone and west zone, 5.7 m and 7.3 m in width respectively; the median zone contains two lanes plus the refuge island which is 8.4 in width. In the beginning of green intervals, there are only pedestrians walking in a single direction at both the east zone and the west zone. For about 5 seconds later, when pedestrians start stepping into the median zone, they start to create many interactions. A few seconds later, the flow became single direction on the east zone and the west zone again. Therefore, we divided the crossings into three zones to describe the density of the flow more accurately.

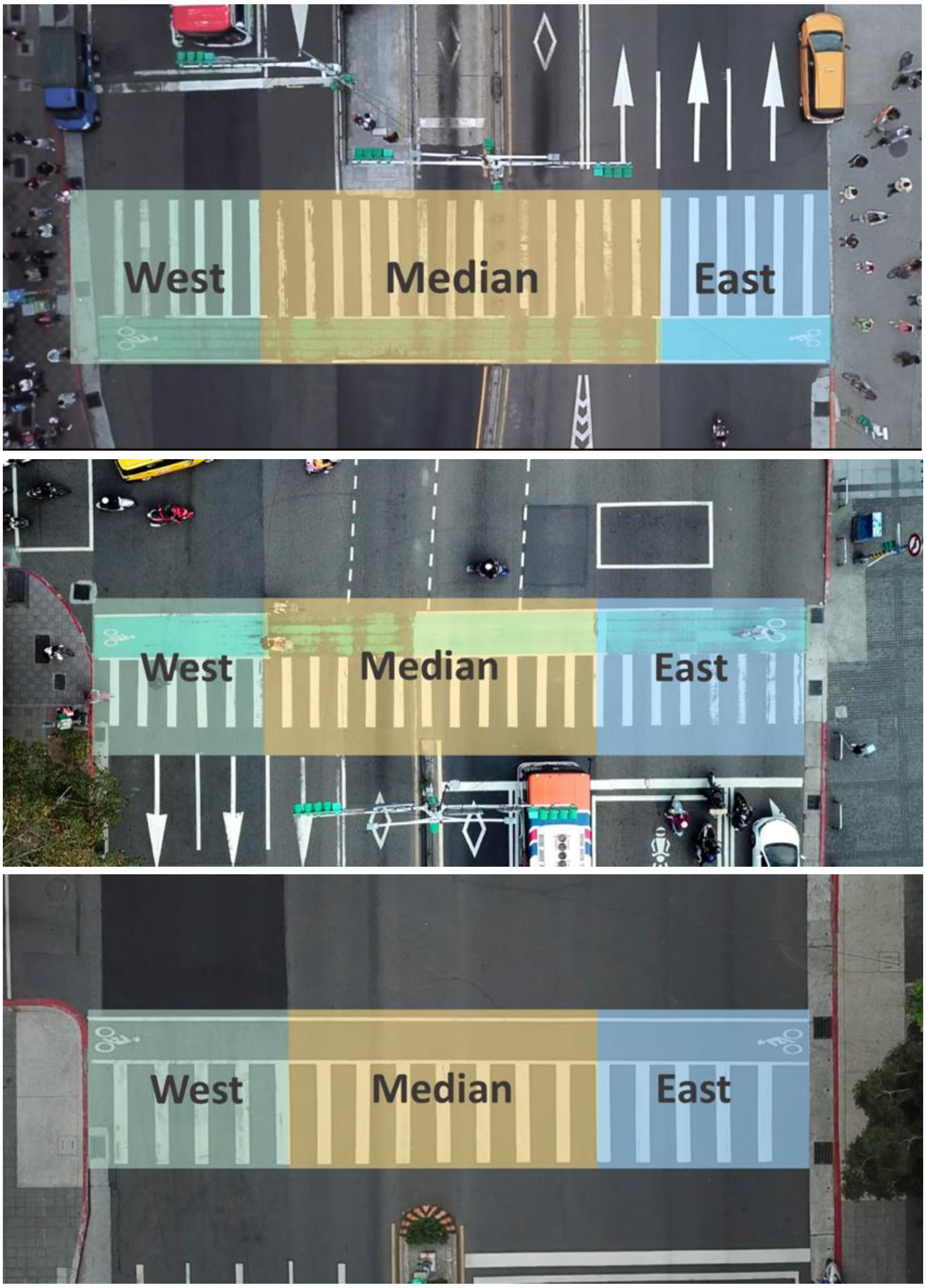

Figure 7. Illustration of the divided zones of the crossings. (a) Crossing 1; (b) Crossing 2; (c) Crossing 3.

Not only does space we divided into three parts, we also divided the green intervals into smaller time intervals. For better determining the conflict events, each green interval is divided into several time intervals according to the density variation during the whole green interval. We observe from the video that in the first 20 seconds of a green interval, most of the pedestrians who waited before the signal turned green has already stepped into the last zone, which means they almost finished the crossing and completed the interactions with the road users from the opposite direction. Also, all the cyclists who started to cross at the beginning finished their crossing in the first 20 seconds. Therefore, we used 20 seconds as an interval. Crossing 1 has three time intervals in one green interval in morning peaks: 0-20 seconds, 20-40 seconds, 40-60 seconds, two time intervals in off peaks: 0-20 seconds, 20-40 seconds, and two time intervals in evening peaks: 0-20 seconds, 20-42 seconds; Crossing 2 has three time intervals in one green interval in morning peaks: 0-20 seconds, 20-40 seconds, 40-65 seconds, two time intervals in off peaks: 0-20 seconds, 20-44 seconds, and three time intervals in evening peaks: 0-20 seconds, 20-40 seconds, 40-56 seconds; Crossing 3 has two time intervals in one green interval in morning peaks: 0-20 seconds, 20-45 seconds, two time intervals in off peaks: 0-20 seconds, 20-35 seconds, and two time intervals in evening peaks: 0-20 seconds, 20-40 seconds.

The location data were simply noted in zones and on pedestrian crossings or bicycle crossings. These data are used to describe the place where conflict events happen and describe the flow and density in the zone when a conflict event happened. The speed data of each road users are transformed from time and recorded in three zones respectively. The corresponding times taken by pedestrians and cyclists in each zone was obtained by noting the entry and exit frames and corresponding times. Pedestrians and cyclists were timed at four moments: (1) when they stepped/rode onto the crossing (started the first zone crossing); (2) when they stepped/rode onto the median of the crossing (started the median zone crossing); (3) when they stepped/rode onto the last zone of the crossing (started the final zone crossing); (4) when they left the crossing. The crossing speed was calculated by dividing the length of each zone by the time the road user took to cross the distance of this zone. The time for the four moments and crossing speed were then stored in a computer file for analysis. All the video streams were viewed by the same observer to ensure the same perspective of identifying conflict events.

2.2 Data Analysis

2.2.1 Conflict indicator selection

With the occurrence of traffic accidents and their consequences, the study of traffic safety has been concerned. Traditionally, researchers used accident data for analysis. However, accidents are rare events and can seldom be systematically observed and recorded. (Malmö, 1984) The accident frequency is too low to permit reliable analysis in many cases. Perkins and Harris (1967) designed to develop an indicator by which traffic accidents could be predicted, and which could be also employed in order to obtain a better insight into causal factors. They identified potential accident situations, termed “traffic conflicts”.

Traffic conflicts were identified by the occurrence of evasive actions, such as braking or swerving, which are forced on a road user by an impending accident situation or by a traffic violation. Researchers have made clear definition at the first Workshop Conflict Techniques Oslo (1977): **“***A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged.*” To estimate traffic conflicts, there are more than 20 types of conflict indicator been developed, the most commonly used indicators are "time to collision (TTC)" and "post-encroachment time (PET)." TTC at an instant time is defined as '*the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained*' (Hydén, 1996). The obtained minimum TTC during the approach of two conflict participants is taken as an indicator of the severity of a conflict event. In principle, the smaller value the minimum TTC is, the higher the severity of a conflict event will be. PET was defined as *'the time difference between the moment an "offending" vehicle passes out of the area of the potential collision and the moment of arrival at the potential collision point by the "conflicted" vehicle possessing the right-of-way'* (Cooper, 1984). To measure PET, one needs to know only two time points: when the first vehicle leaves the right-of-way infringement zone and when the second vehicle enters the right-of-way infringement zone. However, in most of pedestrian-cyclist and cyclist-cyclist conflict events, the conflict participants don't pass through a particular collision point, they swerve to avoid collisions. Therefore, using PET as a conflict indicator would ignore many potential conflicts which would be unable to reflect real data. For the reason outlined above, we choose TTC as the conflict indicator in this study.

According to the aforementioned definition of TTC, we treat the change of the crossing direction of road users and the change of speed difference between conflict participants as evasive actions. We first select every evasive action observed in the recorded video streams which may represent a potential conflict and then estimated the minimum TTC. To determine the severity of a conflict event, a critical or threshold value should be chosen. Generally, TTC lower than the perception and reaction time is considered unsafe. Researchers have studied the value of TTC in various situations. (Sayed et al., 1994; Van der Hors, 1990; and Vogel, 2003) The reported minimum critical threshold TTC value is between 1 second to 2 seconds, and the desirable value is 1.5 to 3.5. The speed, behavior, and stopping distance of pedestrians and cyclists are totally different from vehicles. However, all of these threshold TTC values are for conflicts of vehicles, and there were no studies about TTC values in the conflicts of cyclists or the conflicts between pedestrian and cyclist. Although we were not able to identify the threshold TTC value, we selected the conflict events from observed evasion actions using the minimum TTC value range from 0 seconds to 3.5 seconds according to the previous studies.

2.2.2 Types of conflicts

From the Malmö study (1984), conflicts were classified as follows: rear-end, weave or merge, right angle, head on, left turn, right angle with turn, u-turn, double turn, pedestrian, and other. Some of these conflict types are not appropriate to apply on pedestrian-cyclist or cyclist-cyclist crossing conflicts. Therefore, we reserved rear-end, weave or merge, and head on, these three conflict types. Furthermore, conflicts are also classified as the same direction, opposing left turn, cross traffic, right-turn-on-red, pedestrian, and secondary from Traffic Conflict Techniques for Safety and Operations-Observers Manual (Federal Highway Administration, 1989). The concept of different directions was then added into our classification to distinguish pedestrian and cyclist flows from two sides during their crossing.

Beitel et al. (2016) studied cyclist-pedestrian interactions in shared space. They classified conflict types according to the angle between interaction trajectories. Three types of interactions between cyclists and pedestrian were designed in their research: Type 1 interactions named "crossing from behind" or "overtaking", involving trajectories in the same direction plus or minus 30 degrees; Type 2 interactions considered as "crossing from ahead" or "head-on", featured by trajectories intersecting in opposite direction plus or minus 30 degrees; Type 3, "crossing from the side" or "angled", including all other interactions. We considered the concept of angles between interaction trajectories and classified the observed conflict events into three types as below: "head-on" including trajectories in opposite directions plus or minus 30 degrees; "rear-end" involved trajectories in the same direction plus or minus 30 degrees; "sideswipe" contained all other conflict events.

Finally, by classified the observed conflict events using types of the participants, the angle between participants' trajectories, and the crossing directions of the participants. There were 8 types of conflict events in this research as listed below:

- Cyclist-pedestrian head-on conflict in opposite directions
- Cyclist-pedestrian sideswipe conflict in opposite directions
- Cyclist-cyclist head-on conflict in opposite directions
- Cyclist-cyclist sideswipe conflict in opposite directions
- Cyclist-pedestrian rear-end conflict in the same direction
- Cyclist-pedestrian sideswipe conflict in the same direction
- Cyclist-cyclist rear-end conflict in the same direction
- Cyclist-cyclist sideswipe conflict in the same direction

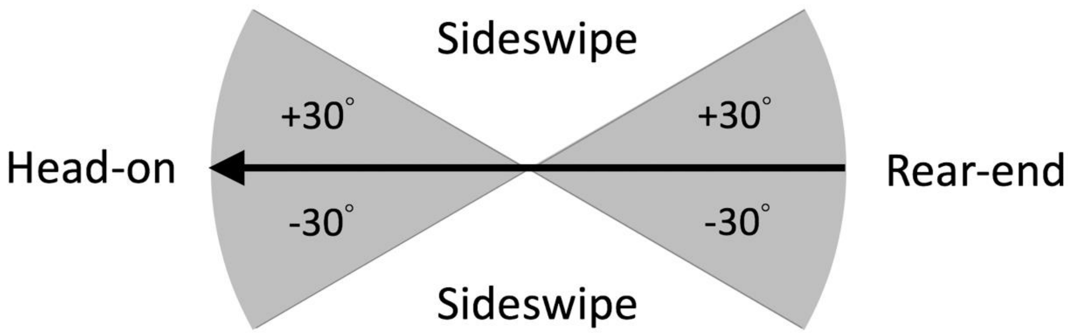

Figure 8. Illustration of the conflict types according to the angle between interaction trajectories

2.2.3 Poisson regression analysis

In this research, we employed a Poisson regression model to investigate the influence factors of different types of conflicts. Poisson regression is a discrete probability distribution with a minimum of zero. Since Poisson regression model is well suited for modeling count data, it is used to explore the conflict events during pedestrian and cyclist crossing behavior in this study.

The basic form of the Poisson regression model is shown below.

$$\boldsymbol{\lambda = e^{\beta x}} \quad (1)$$

where,

λ : dependent variable (number of conflict events),

$\boldsymbol{\beta}$: coefficient,

$\boldsymbol{X}$: independent variables.

$\boldsymbol{X}$ represents the various characteristics that might influence the occurrence of conflicts, include time periods (morning-peak, evening-peak or off-peak), signal timing (cycle length, green interval, and red interval), time interval, width and length of crossings, speed, flow, and density.

3. RESULT

3.1 Observed Conflict Events

The number of conflict events is shown in Table 2. There were 259 conflict events observed in 27 selected cycles, three time periods of each crossing have three cycles been selected respectively. The cyclist-pedestrian head-on conflict in opposite directions is the most frequent event; there are 58 of them, which is accounted for more than one-fifth. The cyclist-pedestrian sideswipe conflict in opposite directions is the second largest type of conflict; which are 47 of them. The interactions between pedestrians and cyclists in opposite directions seem worse, they create 105 events, which is about 40% of the total events. The number of conflict events in opposite direction is 161, more than the conflict events happen between participants in the same direction.

Table 2. Number of different types of conflict events

Conflict type			Number of events
Cyclist-pedestrian	Head-on	Opposite direction	54
Cyclist-pedestrian	Sideswipe	Opposite direction	57
Cyclist-cyclist	Head-on	Opposite direction	32
Cyclist-cyclist	Sideswipe	Opposite direction	19
Cyclist-pedestrian	Rear-end	Same direction	38
Cyclist-pedestrian	Sideswipe	Same direction	24
Cyclist-cyclist	Rear-end	Same direction	15
Cyclist-cyclist	Sideswipe	Same direction	35
Cyclist-motor vehicle			8
Total			283

Figure 9 shows the types and locations of the conflicts in different time period. There is no significant difference in terms of pedestrian flow and cyclist flow between morning peak and off-peak, the small amount of flow in morning peak perhaps because of the variation of the time of the first class. Although 8 am to 9 am is in the morning peaks of vehicle flow, for college students, they might have the first class at 9 am or 10 am, or even do not have class in the morning. This may cause low pedestrian and cyclist flow in morning peak periods. At Crossing 2, the location of conflict events were biased to the east in evening peaks. This resulted from the two-stage left turn box for scooters, which was too close to Crossing 2. The vast amount of pedestrians and bicycles in the evening peak were unable to evade the scooters riding into the two-stage left turn box, so conflicts inevitably occurred. In addition, there was a reason that 90% of the cyclists from east to west were directly turning left into the car lane, because there was no bicycle lane on the opposite sidewalk, and there were obstacles such as transformer boxes and scooter parking spaces on the sidewalk, the conflicts on the west side was significantly less than that on the east side.

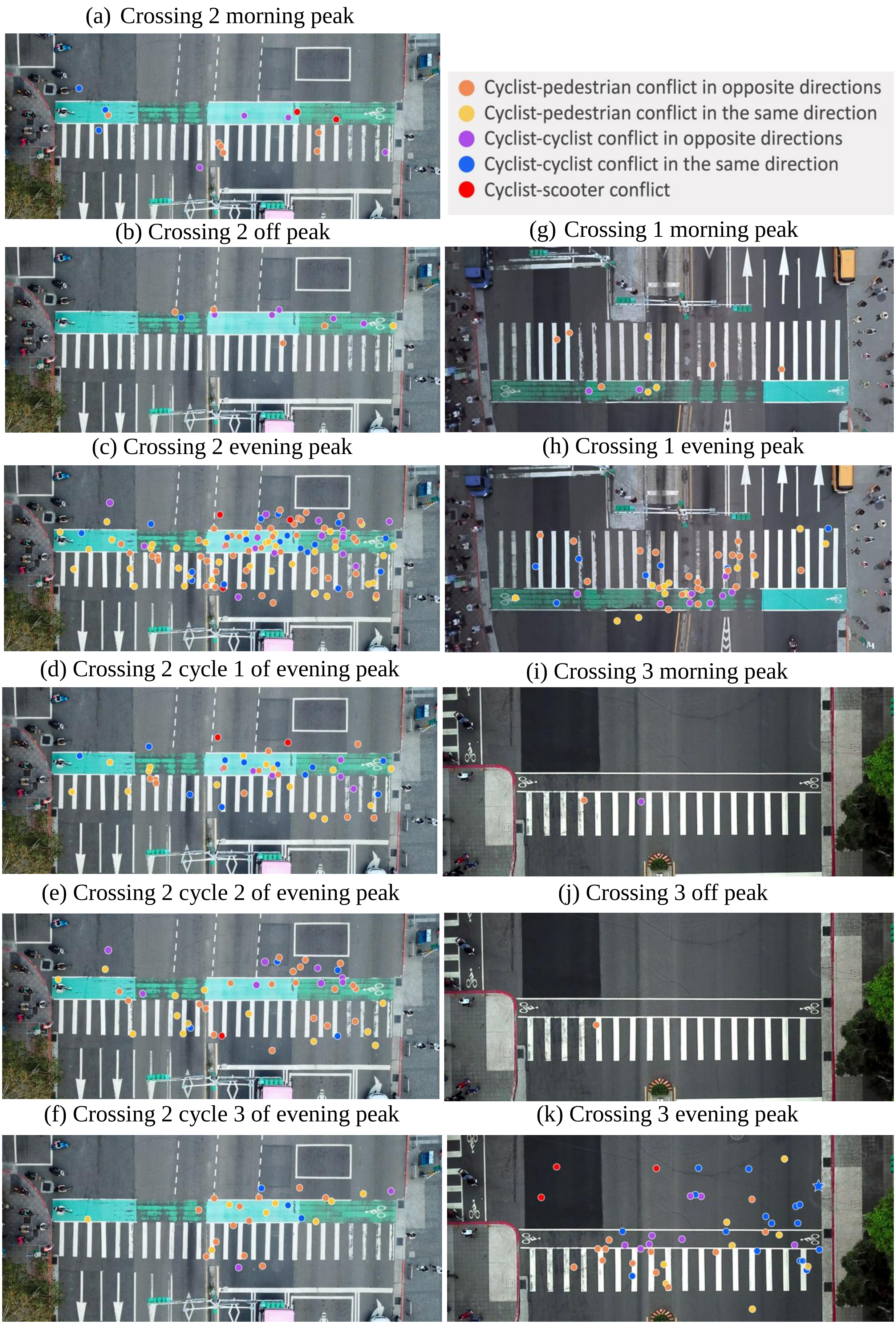

Figure 9. The conflict events position at three crossings in different time period.

A large amount of yellow and orange points are scattered on the bicycle crossing, indicating that many pedestrians were walking on the bicycle crossing. In contrast, Crossing 3 was more peaceful. The location of the conflicts is scattered, but most of the conflicts also located on the bicycle crossing. At this T-road, pedestrians and cyclists often go directly to the sidewalk at the top left of the photo, which is a direct diagonal crossing. Here we can see that many conflict points are on the bicycle crossing and outside the bicycle lane.

Table 3. Amount and average speed of pedestrians and cyclists

Crossing 1	Pedestrian			Cyclist			Conflict Events
	Westbound	**Eastbound**	**Avg. speed**	**Westbound**	**Eastbound**	**Avg. speed**	
Morning peak	37	89	1.25 m/s	5	28	2.52 m/s	13
Off peak	14	29	1.37 m/s	5	7	2.96 m/s	0
Evening peak	151	103	1.08 m/s	31	22	1.79 m/s	54
Crossing 2	**Pedestrian**			**Cyclist**			**Conflict Events**
	Westbound	**Eastbound**	**Avg. speed**	**Westbound**	**Eastbound**	**Avg. speed**	
Morning peak	5	23	1.62 m/s	9	34	3.21 m/s	17
Off peak	10	30	1.40 m/s	17	22	2.94 m/s	15
Evening peak	132	86	1.18 m/s	53	27	1.76 m/s	126
Crossing 3	**Pedestrian**			**Cyclist**			**Conflict Events**
	Westbound	**Eastbound**	**Avg. Speed**	**Westbound**	**Eastbound**	**Avg. speed**	
Morning peak	5	22	1.43 m/s	9	14	2.73 m/s	3
Off peak	5	8	1.22 m/s	3	4	3.93 m/s	1
Evening peak	68	41	1.18 m/s	46	35	2.00 m/s	53

* Both the eastbound of three crossings are the direction to the campus.

The amount and average speed of pedestrians and cyclists are listed in Table 3. It can be seen that the peak flow is significantly larger than the morning peak and the off-peak. The average speed of cyclists in evening peak at Crossing 2 is significantly lower than other time periods, showing the impact of pedestrian flow. The speed variation in these three time periods had a subtle relationship with the flow and flow ratio of pedestrians in two directions. This indicates that not only the more pedestrians but the speed of cyclists will decrease. When the pedestrian flow in two directions are nearly equal, the mixed flow will also slow down the cyclists. At Crossing 3, the cyclists had also been affected during the evening peak, but was not that serious compared to Crossing 2. It was probably because of the more substantial bicycle flow, the cyclists formed a mode that most of the cyclists kept in the same speed and followed orderly, this situation is similar to the vehicle fleet, which made these cyclists passed smoothly, and the pedestrians chose not to walk directly to this bicycle flow.

Table 4 shows the number of events with TTC in different ranges. In a vehicle conflict event in previous studies mentioned in section 2.2.1, the minimum critical threshold TTC value is between 1 to 2 seconds, which means that TTC less than 1 to 2 seconds is regarded a serious incident which could cause a collision.

Table 4. Number of events of TTC in different range

TTC Range (s)	Number of events
$0 < TTC \le 0.5$	44
$0.5 < TTC \le 1.0$	117
$1.0 < TTC \le 1.5$	90
$1.5 < TTC \le 2.0$	24
$2.0 < TTC$	8
Total	283

However, there is no related research on the classification of TTC and severity for cyclist-pedestrian or cyclist-cyclist conflict. In Table 4, it is observed that most of the events are less than 2 seconds. There were 222 of 259 events has TTC value less than 1.5 seconds, almost 86% of the conflicts; 135 of 259 events has TTC value less than 1 second, which is 52%. That is to say, there is a big difference between cyclists-pedestrian conflicts and vehicle conflicts. Because of the slower speed and the higher flexibility of pedestrians and cyclists, 1 to 2 seconds may not be appropriate to apply to the threshold of cyclists-pedestrian and cyclist-cyclist conflicts severity. How to quantify the severity will be continued studying in the future work.

3.2 Poisson Reggression

Table 5. Variables of the Poisson regression model

Notation	Variable	Description
Dependent variable		
C_{ijkl}	Conflict events	Number of conflict events of type *i* at Crossing *j* in period *k* time interval *l*.
Independent variable		
C_OPCH	Conflict type-OPCH	Binary variable, cyclist-pedestrian head-on conflict in opposite directions.
C_SPCR	Conflict type-SPCR	Binary variable, cyclist-pedestrian rear-end conflict in the same direction.
C_SPCS	Conflict type-SPCS	Binary variable, cyclist-pedestrian sideswipe conflict in the same direction.
TI1	Time interval 1	Binary variable, the first time interval (0-20s) in a green cycle.
PDF_{jk}	Pedestrian flow	Pedestrian flow of Crossing *j* in period *k*. (Unit: people/cycle)

Table 6. Model estimation

Independent Variables	Coefficient	Standard Error	T-ratio
C_OPCH	0.73	0.19	3.740
C_SPCR	0.55	0.22	2.517
C_SPCS	-1.23	0.59	2.070
TI1	0.27	0.17	1.624
PDF	0.02	0.004	5.359

Table 5 shows the dependent variable and the significant independent variables. There are three conflict types significant, *C_OPCH* and *C_SPCR* have positive coefficients, which represents that they occurred the most, and *C_SPCS* has negative coefficient shows that it was the least occurred conflict type. *TI1* and *PDF* are significant mean that conflicts tend to appear in the first 20s of the signal cycle, and they increase as pedestrian flow increase.

4. CONCLUSION

To develop safer and friendlier environments for cycling and walking has received increasing attention to foster sustainable transportation, particularly from the perspective of transforming street design. Many cities have deployed dedicated bike lanes to separate cyclists from other traffic flows in light of the described development trend and safety concerns. However, the effectiveness of dedicated bike lanes is questioned or even criticized in terms of their utilization rates. It is frequently observed that some cyclists still ride on the areas of pedestrian walkways, even though dedicated bike lanes are available right aside; on the contrary, there are also the cases that pedestrians walk on dedicated bike lanes. As cyclists and pedestrian are still significantly different from each other in terms of their movement characteristics, conflicts or even collisions between cyclists and pedestrians seem to remain. This research seeks to explore the behavioral patterns related to cyclist-pedestrian conflicts against the presence of dedicated bike lanes, so as to provide both empirical and quantitative insights for the current design guidelines. We film video streams over the signalized crossings around a university campus in Taipei, Taiwan. Heavy cyclist and pedestrian traffic can be observed at the selected signalized crossings, as college students can be one of the major cyclist groups.

Based on the recorded video, this research abstracts the trajectories of cyclist and pedestrian flows to identify the aggregate behavioral pattern of crossing streets with the presence of dedicated bike lanes. Eight conflict types have been classified, and 259 conflict events were observed. The Poisson regression model was employed, it showed that conflicts tend to appear in the first 20s of the signal cycle, and they increase as the pedestrian flow increase. Among all the conflicts, cyclist-pedestrian head-on conflict in opposite directions and cyclist-pedestrian rear-end conflict in the same direction are the most. The average crossing speed of cyclists is significantly influenced by pedestrian flows, as observed during the evening peaks, which also implies a lower service level for cyclists.

5. FUTURE RESEARCH

Future studies will consider taking more crossings and more cycles into account for the sake of higher accuracy of the research. Furthermore, mixed logit model will be applied to this research in purpose of comparing results from Poisson regression model. For the variables, we will include some new variables such as, waiting location, starting location, ending location, mixing ratio of cyclist and pedestrian, and flow ratio of two directions, which will be added into the models. Besides, we would like to create more appropriate conflict indicators so as to estimate conflicts and their severities more accurately and effectively.

After finishing the works mentioned above, we will propose a new geometric design of intersections specially for the ones with larger amount of pedestrians and cyclists and we expect that the new design will alleviate the conflicts of those intersections.

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