AUT Journal of Civil Engineering

AUT J. Civil Eng., 4(3) (2020) 357-366
DOI: 10.22060/ajce.2019.16486.5591

Investigating the influential factors in changing the likelihood of involving pedestrians in dangerous situations

M. Shafaati[1], A. M. Boroujerdian[2,*]

[1] Department of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran
[2] Assistant Professor, Faculty of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran

ABSTRACT: Analyzing the pedestrian safety without using the accident data has become common in the recent years. Investigating the pedestrian safety based on the conflict idea is becoming popular. Therefore, this paper has investigated variables that cause interaction between vehicles and pedestrians for pedestrians, to be potentially dangerous and possibly critical situation. Two measures were used in this study: Time to Collision (TTC) and Post-Encroachment Time (PET). First, an unsignalized intersection was chosen to launch this study. The site was filmed by camera for about 8 hours in two days. The different steps of this study were: identifying the conflict situations, tracking pedestrian and vehicles and then obtaining the PET, TTC, and the other data using MATLAB.
Probit models have been developed for analyzing the desired variables. There are 488 and 519 observations in TTC and PET models, respectively. In models with TTC being the dependent variable, the mean pedestrian and vehicle speed and the direction of pedestrian movement were some variables that cause an interaction to be potentially dangerous for pedestrians. Furthermore, in models with PET being the dependent variable, mean vehicle and pedestrian speed, number of pedestrians, and the direction of vehicle movement were some factors that lead a conflict to possibly critical situation for pedestrians.

Review History:

Received: 2019-06-18
Revised: 2019-09-25
Accepted: 2019-11-13
Available Online: 2019-11-26

Keywords:

The Pedestrian Safety
Surrogate Safety Measures
The Post-Encroachment Time
Time to Collision

1. INTRODUCTION

More than 1.25 million people lose their lives every year due to traffic accidents in the world. Collisions are the main reason of death for those who are aged between 15 and 29. Half of these people are vulnerable road users, including pedestrians, motorcyclists, and cyclists [1]. Pedestrians are one of the most vulnerable users on the road because of lack of protection, visibility, and the auto-dominated culture [2]. If pedestrians are involved in vehicle crashes, they are more likely to end up with severe injuries and fatalities compared to motorcyclists and cyclists [3]. Even in the developed world the pedestrian safety is a serious concern, for example in China, according to The Ministry of Public Security, pedestrians accounted for 30% of total traffic fatalities in 2011. So Pedestrian safety has become a significant worldwide concern in recent years [4]. Intersections all over the world have a considerable share of such incidents. They are the most critical roadway elements with high concentration of vehicle-pedestrian crashes [5]. For example, in the US, almost 50% of injury accidents and about 30% of fatalities occur at intersections. Also, 24% of fatal accidents in the EU occur at intersections [6]. To analyze pedestrian safety at intersections, historical collision data is used usually, however, this method bears some disadvantages [7]. It is suggested that any studies based on police crash data might be completely confusing [8]. For instance, in 1995, about one-third of the people injured or killed in traffic crashes were not reported by the police [9]. Also, it has been mentioned that the number of fatalities and injuries in road accidents might be significantly higher than the official statistics reported by the police or other responsible bodies [10]. Given the fact that accident data reported by the police often leads to problems among vulnerable road users, especially cyclists [9,11], the number of accidents and fatalities are usually biased against vulnerable road users. For example, it was realized that the actual number of bicycle accidents are two times as the official report in the city Munster in Germany [12]. In addition, police may make mistakes while transferring data from paper to electronic databases [13, 14, 15, 11]. Besides, their data lack some information such as speed and the exact location of the accidents [16, 14, 17]. Overall, crash data suffer from known issues such as low-mean small sample, underreporting, dislocation, and misclassification. In order to solve the problems with historical crash data, proactive methods have been proposed that rely on surrogate measures of safety [18]. Therefore, developing newer techniques based on the idea of conflict is necessary. As a new idea, the surrogate safety approach could replace the long return period of collision observations. In fact, it can be done by using the observations of road user interactions under driving conditions. An interaction between road users, can be defined as the relationship between pairs of road users [19]; in other words, a situation where the road users are close enough in time and space such that they might interact with

*Corresponding author's email: boroujerdian@modares.ac.ir

each other [20].

Few studies have analyzed pedestrian-vehicle interaction based on surrogate safety measures, especially in non-signalized crosswalks. Not many studies have used effective variables to identify dangerous and critical conflicts using Probit or Logit models, to the best of our knowledge. Furthermore, it seems that there are some essential variables which need to be focused on. The variables which contribute to making interactions between vehicles and pedestrians, critical and dangerous according to the The Dutch Manual for Conflicts Observation. It is necessary for researchers and experts who work on safety of transportation to understand how the characteristics of vehicles and pedestrians may cause a critical situation out of a conflict. This understanding might help them identify and analyze the most important challenges related to pedestrian safety.

This research aims to address these gaps of previous research on pedestrian safety. In fact it provides insight to better understanding of the factors which might influence pedestrians' conflicts with vehicles at unsignalized intersections. The main purpose of this paper is to investigate and analyze variables which can increase or decrease the likelihood of interactions being critical or potentially dangerous.

2. LITERATURE REVIEW

A great number of research has been conducted for vehicle safety whereas the number of research on pedestrian safety is significantly lower, especially in relation to surrogate safety measures for pedestrian-vehicle interactions at cross-walks [3]. Some scientists believe approximately 3000 conflicts occur before an accident, hence using methods based on conflicts can be useful [21]. Methods developed for a pedestrians' safe travel in urban areas are becoming more sophisticated. For example, Hannah et al. were able to develop a linear model of pedestrian safety that could accurately estimate the number of pedestrian casualties. This model can be used to recommend paths that are safer with respect to road crashes [22]. Lee et al. suggested that the identified exposure-relevant factors that affect pedestrian safety are the presence of schools, car-ownership, pavement condition, sidewalk width, bus ridership, intersection control type, and the presence of sidewalk barrier [23]. Almodfer et al, showed that shorter waiting times and smaller waiting areas strongly influence the lane-based pedestrian-vehicle conflicts at a non-signalized marked crosswalk. The research also suggests that walking speed does not affect lane-based pedestrian-vehicle conflicts [24].

Fu et al. 2016 showed that pedestrians are exposed to higher risk levels at nighttime in comparison to daytime. The reasons are higher vehicle crossing speeds as well as higher percentage of dangerous conflicts at nights [18]. Based on the research, carried out by Lord et al, conflicts and accidents have a significant relation and a direct correlation with each other at intersections [25]. Akin et al. collected data from three signalized intersections in Michigan, USA. In this study, the conflict frequency had a linear relation with the hour volume of left-turn vehicles and hour volume of pedestrians [26].

Cheng et al, found that the volume of pedestrians, the number of left-turn vehicles, and the proportion of pedestrians with a particular condition such as being old, influence the number of conflicts between left-turning vehicles and pedestrians in signalized intersections [27]. Saulino et al. suggested a method in which the number of conflicts is calculated using a simulator. In their study, traffic volume and the speed of each road user significantly influence the number of conflicts [28]. Yagil et al. suggested that the conflict rate for men is more than women [29]. In a study in 2001, it was proved that as the lanes become wider, the conflict rate with left-turning vehicles increases [30]. In 2016 in a study, it was proved that number of conflicts has a direct relation to the density of pedestrians and the volume of right-turn vehicles [31]. Conflict intensity was investigated in 2016 in Poland. In this research, results proved that conflict intensity has a nonlinear relation with the minimum distance between vehicles and pedestrians at an interaction [32].

Ismael et al categorized traffic events occurring between pedestrians and vehicles in three main types: traffic conflicts, important events, and uninterrupted passages. They also believed that Post Encroachment Time (PET) could be considered the commonest measure for recognizing traffic conflicts and important events [33]. Two surrogate safety measures are focused on in this article: Time to Collision (TTC), and Post-Encroachment Time (PET).These measures will be explained in the methodology section.

In this paper, the term "interact" is used instead of "conflict" because it has a more general meaning. Some other studies like [3] have done the same.

It has been only focused on one location in this research. It is not the first time that a single location is used by researchers to study conflicts. In many studies such as [24] which is about lane-based pedestrian-vehicle conflict, only one site was used and studied. Muley et al used only one location to study Pedestrians' crossing behavior as well. The number of observation in their study was 235 [34]. Also, according to [35], many studies about conflicts use a single observation site. In a study which is about pedestrian-vehicle conflicts in the year 2016, only one location has been focused on too [36]. To the author's knowledge, there are no vital rules on the number of locations required for a particular study. This issue may be of low significance. It seems that what matters in the reliability of these studies is having a data-base with a high number of observations. The number of observations for each individual model in this article is more than 480 and in some cases it reaches 519 observations. Furthermore, the main reason why some researchers choose to study more than one location is to obtain the variability needed for reliable results. This enables the observation to consist of different traffic situations and road geometries. It seems that having a location of which there are many observations in different hours of the day, provides different traffic situations of both pedestrians and vehicles. Thus, at least one problem with a one-site study can be resolved by recording different hours of the day. Nevertheless, the issue of geometry still remains, however, if investigating the geometry variables is not a goal of a study, such as this paper, this problem can be ignored. Therefore, it seems that one location can be considered sufficient for the goals of this paper.

3. METHODOLOGY

In this research, an Unsignalized X intersection was chosen to study pedestrian safety. This intersection connects two streets called Vesal-Shirazi and Bozorgmehr in Tehran, Iran. This intersection has some advantages, such as high number of interactions and conflicts between vehicles and pedestrians. The advantage here means that by higher number of conflicts, the data-base consists of more observations. The more observation can make it possible to have more precise statistical results which could lead to more concrete findings. The slope of all approaches are the same: 0 degrees, and the angle of the intersection is 90 degrees. For the purpose of recording, the camera was installed on the roof of a six-flour building with a height of about 17 meters. In this intersection, the major street is Vesal Shirazi and the minor is Bozorgmehr. The major and the minor streets consist of three and two lanes respectively, and both have a median. In fig. 1, the intersection can be seen on an image acquired from Google maps.

Content was recorded on June 2017 in two days. The weather was sunny and the pavement of the intersection was dry. Filming took place during daylight, before sunset. Eventually, eight hours of video clips were achieved. Identifying the conflicts in this study was done based on the DOCTOR method. In this method, an event is considered a conflict only if one party involved has to take an action to avoid collision [37, 38]. Therefore, basically all interactions between cars and pedestrians with at least one of these characteristics considered a conflict in this study: a vehicle increases or decreases its speed due to encountering one or more pedestrians, one or more pedestrians increase or decrease their speed because of encountering a vehicle, a vehicle changes its path to avoid hurting one or more pedestrians, and one or more pedestrians change their path to avoid a vehicle.

Suppose that Tc1 and Tc2 are the time when the vehicle enters and leaves the conflict zone and Yp1 and Yp2 are the time when the pedestrian enters and leaves the conflict zone

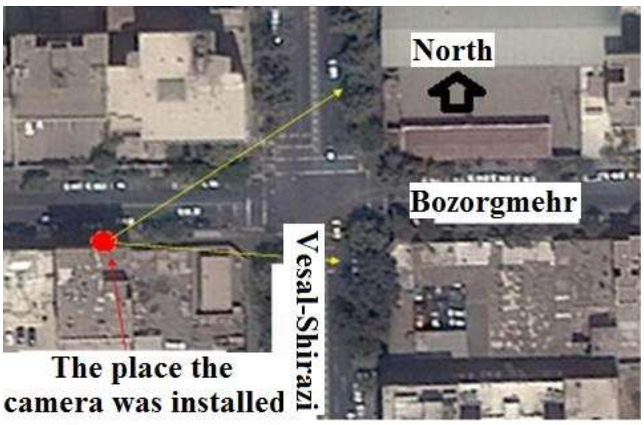

Fig. 1. The unsignalized intersection

respectively, t0 is the moment of taking the evasive action, I is the time point of the conflict process, and i ε [t0, min (Tc,Tp)], dc (i) is the distance from the front of vehicle to the extrapolated outline of the conflicting pedestrian at time i, dp(i) is the distance from the pedestrian to the extrapolated outline of the conflicting vehicle at time i; vc (i) and vp(i) are the speeds of the conflicting vehicle and pedestrian at time I, respectively; l is the length of the conflicting vehicle, and w is the width of a vehicle. The way, PET, TTC are calculated are as follows [4]:

Post-Encroachment Time (PET):

If a pedestrian passes first, PET= $T_{c1} - T_{p2}$ (1)

If a vehicle passes first, PET= $T_{p1} - T_{c2}$ (2)

Time to Collision (TTC) [4]:

If a pedestrian passes first, $TTC(i)=\max(\frac{dp(i)+w}{vp(i)},\frac{dc(i)}{vc(i)})$ (3)

If a vehicle passes first, $TTC(i)=\max(\frac{dp(i)}{vp(i)},\frac{dc(i)}{vc(i)})$ (4)

$TTCmin=\min(TTC(i))$ (5)

The time of conflicts were noted. Tracking and extracting data was done using image processing method and computer programming. In order to calculate the pedestrian and vehicle speed and the measures like TTC and PET a code running in the MATLAB was used. Finally, 519 observations for PET and 488 observations for TTC were obtained. Probit regression models were used to analyze the most influential variables that make conflicts dangerous and critical for pedestrians. Finally the data analysis was done using Probit models.

In summary the steps of the study are:

a) Choosing an unsignalized intersection as the study location.
b) Placing the camera on a relatively tall building to have a good view of the location.
c) Recording the video clips from the intersection.
d) Observing the video clips in order to find the interactions between vehicles and pedestrians.

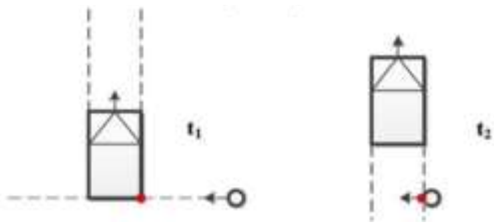

Fig. 2. The pedestrian and the vehicle in calculating the PET

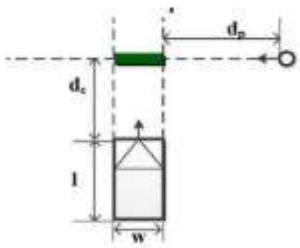

Fig. 3. The pedestrian and the vehicle in calculating the TTC

e) Tracking the conflicting pedestrians and vehicles and noticing the characteristics of the vehicles and pedestrians which are involved in the conflicts.
f) MATLAB programming to calculate the PET, TTC, pedestrian speed, and vehicle speeds.
g) Preparing the data to import them into the statistical software.
h) Running the models and interpreting them.

4. RESULTS

The Dutch Manual for Conflicts Observation (DOCTOR) has pointed that a minimum TTC value of less than 1.5s indicates a potentially dangerous situation in urban areas, and PET values of 1.0 and lower indicate a possibly critical traffic situation [38]. Therefore, binary Probit or Logit models can be used to analyze the most important variables which might make conflicts critical and dangerous. In this study, observations with PETs that are less than 1 second are considered 0 and PETs that are more than 1 second have been considered 1. Furthermore, according to DOCTOR, TTCs less than 1.5 seconds are considered 0 and higher than 1.5 seconds were considered 1. In this article, two series of Probit models have been developed.

4.1. Results of models with TTC being a dependent variable

In Table 1, the variables used in this model have been introduced.

The results of the Probit model based on TTC is shown in Table 2.

In this database, TTCs are less than 1.5 seconds in approximately 27% of observations. In this model, 365 observations have been estimated correctly, this number is equivalent to %73 of the whole data. Only the signs of the coefficients in Table 1 can be analyzed. To analyze the coefficients, marginal effects must be calculated.

4.2 Results of models with PET being a dependent variable

In this section, variables which can possibly make conflicts critical have been investigated. As mentioned before, PETs are equal to 1.0 and lower represent a possibly critical traffic situation. Like models with TTC being a dependent variable, a Probit model are developed to analyze the critical conflicts

Table 1. The variables used to develop Probit model with TTC being the dependent variable

TTC*	The minimum amount of time to collision in terms of seconds.
Vmean-vehicle	The average speed of a vehicle during the interaction.
Vmean-ped	The average speed of pedestrians during the interaction
Straight	A dummy variable which is considered 1 if the of movement direction the vehicle is straight and 0 if it is not.
Taxi	A dummy variable considered 1 if the vehicle is taxi and 0 if it is not.
NoP	The number of pedestrians crossing the conflict zone.
Direction	A dummy variable considered 1 if one or a group of pedestrians gets engaged in a conflict while crossing the conflict zone from left to right and 0 if they cross from right to left.
NS	A dummy variable explaining if the pedestrian engaged in a conflict has to stop in order to avoid another vehicle coming immediately after the first vehicle or not. If they do stop, the variable is 1, otherwise, it is 0.

Table2. Probit model for TTC being the dependent variable

Iteration 0: log likelihood= -287.7986				Number of observations = 488		
Iteration 1: log likelihood= -261.13677				LR chi2 (7) =53.70		
Iteration2: log likelihood= -260.94815				Prob > chi2 = 0.0000		
Iteration3: log likelihood= -260.94808				Pseudo R2= 0.0933		
Iteration4: log likelihood= -260.94808				Log likelihood= -260.95		
TTCdangerous	Coef.	Std.err	Z	p>|z|	[95 conf.	Interval]
Vmean_vehicle	-0.30	0.06	-5.36	0.00	-0.40	-0.19
Vmean-ped	-0.43	0.20	-2.13	0.03	-0.82	-0.03
Straight	0.54	0.16	3.30	0.00	0.22	0.86
Taxi	0.36	0.16	2.30	0.02	0.05	0.67
NoP	-0.27	0.10	-2.57	0.01	-0.47	-0.06
direction	-0.28	0.14	-2.02	0.04	-0.55	-0.01
NS	0.62	0.27	2.28	0.02	0.09	1.15
Cons	2.24	0.36	6.23	0.00	1.54	2.95

Table 3. The variables used to develop Probit model with PET being the dependent variable

PET *	The amount of the Post-Encroachment Time in seconds.
Vmean-vehicle	The average speed of a vehicle during the interaction.
Vmean-ped	The average speed of pedestrians during the interaction
Left-turn	A dummy variable considered 1 if the vehicle is left-turning and 0 if it is not.
NS	As introduced before, it is a dummy variable explaining if the pedestrian engaged in a conflict has to stop in order to avoid another vehicle coming immediately after the first vehicle or not. If they do stop, the variable is 1, otherwise, it is 0.
H	Defined by crossing Vmean-ped to left-turn. This variable is used to analyze the interaction between left-turn vehicles and pedestrians.

Table 4. Probit model for PET being a dependent variable

Iteration 0: log likelihood= -355.66235						
Iteration 1: log likelihood= -327.72904				Number of observations = 519		
Iteration2: log likelihood= -327.658				LR chi2 (7) =56.01		
Iteration3: log likelihood= -327.658				Prob > chi2 = 0.0000		
Log likelihood= -327.658				Pseudo R2= 0.0787		
PETcritical	Coef.	Std.err	Z	p>|z|	[95 conf.	Interval]
Left_turn	1.08	0.48	2.24	0.03	0.13	2.03
Vmean_vehicle	-0.12	0.04	-2.85	0.00	-0.21	-0.04
Vmean_ped	0.93	0.21	4.50	0.00	0.53	1.34
NS	1.39	0.23	5.96	0.00	0.93	1.84
H	-1.12	0.43	-2.63	0.01	-1.96	-0.29
cons	-0.80	0.29	-2.71	0.01	-1.37	-0.22

Table 5. The results of the marginal effects of the Probit model with TTC being a dependent variable

Variable	Dy/dx	Std.err	Z	p>|z|	[95 %	CI]
Vmean_vehicle	-0.09	0.02	-5.85	0.00	-0.12	-0.06
Vmean_ped	-0.13	0.06	-2.16	0.03	-0.25	-0.01
straight	0.16	0.05	3.40	0.00	0.07	0.26
taxi	0.11	0.05	2.33	0.02	0.02	0.20
NoP	-0.08	0.03	-2.62	0.01	-0.14	-0.02
direction	-0.08	0.04	-2.04	0.04	-0.16	-0.003
NS	0.19	0.08	2.30	0.02	0.03	0.34

based on the PET. The variables used to develop this model, have been defined in Table 3.

The results of the Probit model based on PET are shown in table 4.

56% of the observations in this database have PETs equal to 1 or lower. In this model, 350 observations out of 519 observations have been predicted correctly, consisting approximately 68 percent of all observations. The area under ROC curve is 0.6911 which can be approximated equal to 0.7, and according to [39], it is acceptable.

4.3 Discussion

In this part of the article, the results of the developed models are discussed.

4.3.1 Model with TTC being a dependent variable

Table 5 shows the marginal effects of the Probit model.

According to table 5, it can be concluded that:

- If the average vehicle speed increases by 1 unit, the likelihood of TTC not being dangerous will decrease by 0.09 units.
- If the average pedestrian speed increases by 1 unit, the likelihood of TTC not being dangerous will decrease by 0.13 units.
- If the direction of the vehicle movement is straight, the likelihood of TTC not being dangerous will decrease by 0.16 units.
- If the vehicle is a taxi, the likelihood of TTC not being dangerous will increase by 0.11 units.

- If the number of pedestrians increases by 1 unit, the likelihood of TTC not being dangerous will decrease by 0.08 units.
- If the pedestrians engaged in a conflict move from left to right, the likelihood of TTC not being critical will decrease by 0.08 units.
- If the pedestrians have an extra stop after a conflict with a vehicle because of another vehicle passing immediately, the likelihood of conflicts not being dangerous will increase by 0.19 units.

This table demonstrates that if the average speed of the vehicle involved in a conflict increases, the likelihood of the conflict not being potentially dangerous, based on TTC, will decrease. It is the same for average pedestrian speed. These results are logical as the relation between speed and TTC is indirect. The third variable shows that if the direction of a vehicle movement is straight, the interaction is less likely to be dangerous. The reason is in a situation where vehicles have a straight movement, pedestrians can see them easier than when vehicles are left or right-turning. Once the pedestrians encounter with the vehicles moving straightly, they just need to twist their neck right or left to see the vehicle. But imagine a pedestrian is moving from left to right, suddenly a left-turning vehicle, encounters with them, in this case, the pedestrian has to be careful about behind so they need to twist their neck even more than 90 degrees, which makes it very difficult to pass the street. Also, the cars moving straight find it easier to see the pedestrians. In other words, pedestrians who have interaction with this group of vehicles are more visible to the drivers, compared to left or right-turning vehicles. Another reason is related to the driver's workload. Assuming a normal situation where there are no any other vehicles in the intersection except the one which is about to conflict with the pedestrian(s). As shown in fig. 4, vehicles moving straight can pay attention to other streets approaching the intersection more easily. In fact, they don't have to be careful about more than one approaching street at the same time, while left and right-turning vehicles need to see other approaching streets almost simultaneously.It can make conflicts much more dangerous. In fig. 5 and 6, left-turning and right-turning vehicles are shown respectively.

The next variable studies the effect of taxis. According to the results, being a taxi decreases the likelihood of a conflict not being critical. The outcome in this paper about taxis is somewhat consistent with the study done by some other researchers who suggested that taxi drivers, perform better when it comes to avoiding crashes at intersections. The reason is that they are professional as well as experienced drivers [40]. The next variable is the number of pedestrians. When pedestrians cross the conflict zone in a group, the likelihood of the conflicts being dangerous is higher. Some studies about pedestrian behavior such as the one done by Ren et al., conclude that pedestrians in a group often don't look at traffic signals [41], which is somewhat consistent with the results of this paper. Pedestrians in groups not paying enough attention to traffic signals means that they are more likely to put themselves in a dangerous situation. However it is recommended that more studies be done to exactly know the effect of walking in groups and the number of member of the group on pedestrian safety based on conflicts. Because in our observations, there are a few observations with pedestrians walking in a group. There are other studies which suggest the same because of the same reason. For example, some researchers proposed the same when they wanted to analyze the impact of walking in groups on the pedestrians' speed. They believed that "the data observations for group sizes were significantly smaller than individual pedestrian observations, and the study could not distinguish variance in speeds across different group sizes"[42]. The next variable is Direction. This variable is considered 1 if a pedestrian is moving from left to right. The reason is that pedestrians who move from left to right might have interactions with vehicles coming from the street approaching the intersection before the main conflict noticed by the authors of this research, hence this group of pedestrians have a harder situation than those crossing from right to left. According to the Logit model, this left-to-right

Fig. 4. A conflict between straight-moving vehicle and a pedestrian

Fig. 5. A conflict between a left-turning vehicle and a pedestrian

Fig. 6. A conflict between a right-turning vehicle and a pedestrian

Fig. 7. A pedestrian who moves from left to right

movement increases the likelihood of dangerous conflicts happening. Fig. 7 analyzes this group of pedestrians. As it is illustrated, left-to-right moving pedestrians face a more difficult situation in comparison to the right-to-left (Fig. 8) moving pedestrians. Therefore, it is expected that these pedestrians face more dangerous situations than the others do. In fact their higher workload leads them to put in dangerous situation more than the other group of pedestrians.

The next variable is NS. 1 denotes a lower chance of dangerous conflict in this variable, as shown in table 2. The one-way ANOVA shows that the speed of the pedestrians with NS=1 is significantly lower than the pedestrians with NS=0. As the speed has an indirect relation with the TTC, so expectedly pedestrians with NS equal to 1, are less likely to be in dangerous situations. Thus, considering the indirect relation between pedestrian speed and the likelihood of not being dangerous, it is concluded that NS makes conflicts not be dangerous.

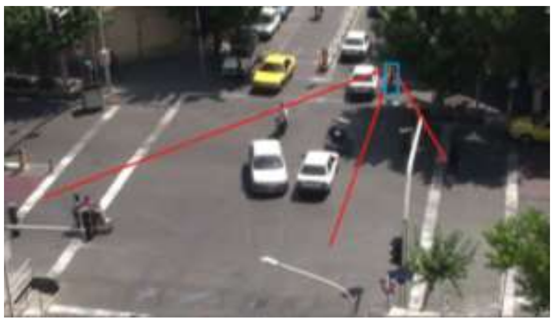

Fig. 8. A pedestrian who moves from right to left

4.3.2 Models with PET being a dependent variable

Table 7 shows the marginal effects of the probit model for PET.

- If the vehicle having a conflict with one or more pedestrians is left-turning, the likelihood of the conflicts not being

Table 6. The one-way ANOVA for analyzing the relation between the pedestrian speed and NS

One-way ANOVA analysis					
Vmean_ped	Sum of squares	Df	Mean Square	F	Sig.
Between Groups	4.714	1	4.714	46.91	0.00
Within Groups	48.84	486	0.100		
Total	53.55	487			
Robust Tests of Equality of Means					
	Statistic	df 1	df 2	Sig.	
Welch	3.815	1	67.93	0.00	

Table7. The marginal effects of the probit model based on PET

Variable	Dy/dx	Std.err	Z	p>|z|	[95 %	CI]
Left_turn	0.39	0.17	2.27	0.02	0.05	0.73
Vmean-vehicle	-0.04	0.02	-2.92	0.00	-0.08	-0.01
Vmean-ped	0.34	0.07	4.77	0.00	0.20	0.48
NS	0.50	0.08	6.62	0.00	0.35	0.65
H	-0.41	0.15	-2.68	0.01	-0.70	-0.11

critical will decrease by 0.39 units.

- If the mean vehicle speed increases by 1 unit, the likelihood of PET not being critical will decrease by 0.04 units.
- If the mean pedestrian speed increases by 1 unit, the likelihood of PET not being critical will increase by 0.34 units.
- If one pedestrian or a group of pedestrians engage in a conflict and has an extra stop because of another vehicle moving immediately after that vehicle, the likelihood of conflict not being critical will increase by 0.50 units.
- If the variable H increases by 1 unit, the likelihood of PET not being critical will decrease by 0.41 units.

Vehicles with a higher speed are more likely to make a conflict critical based on PET. This is a logical result, since vehicles with a higher speed move through the conflict zone and crosswalk faster than others, consequently creating a potential critical conflict according to PET. The first variable explains whether the vehicle is left-turning or not. As stated in the model, if the vehicle is left-turning the likelihood of PET being critical will decrease. Considering the negative correlation between average vehicle speed and being a left-turning vehicle, this group of vehicles have a lower speed and regarding the fact that vehicles with higher speed are more likely to be engaged in a critical conflict, logically, being left-turning would increase the likelihood of PET not being critical.

Table 8 shows the correlation between mean vehicle speed and being left-turning which is in fact, an indirect relationship.

It should be emphasized that, if the relationship between Vmean-vehicle and left-turn is analyzed using the one-way ANOVA, the result is the same.

The variable "Vmean-ped" has a positive coefficient.

Table 8. Correlation between being left-turn and the mean vehicle speed

-------------	Vmean-e	Left-turn
Vmean-vehi-e	1.00	----------
Left-turn	-0.23	1.00

One reason for this result, is that if pedestrians who yield to vehicles have interaction with, stop, so that the vehicle passes the crosswalk first, the pedestrian mean-speed is lower in comparison with the other pedestrians who pass the conflict zone sooner than the vehicle. Now imagine a pedestrian who has waited for the vehicle's moving, immediately after the vehicle's passing, he or she enters the conflict zone, resulting in a very low PET. Therefore there are pedestrians with low mean speed that could have critical PET. Thus the positive coefficient of the variable "Vmean ped" is justified and logical.

The positive coefficient of the variable "NS" is logical. Because the pedestrians who have to stop further because of the other vehicle or vehicles passing immediately after the vehicle which is involved in a conflict with the pedestrians, set foot in the conflict zone later compared to the other pedestrians, resulting in a higher amount of the PET. Thus, these group of pedestrians are more likely not to have critical PETs.

As previously explained, the variable "H" has been determined to investigate the effect of the interaction between pedestrian speed and left-turning on conflicts. An increase in this variable also increases the likelihood of conflicts not being critical. In one hand, left turning vehicles, because of their lower speed, make the situation more likely be normal in our data set. However, on the other hand, the nature of left-turning is a somewhat dangerous movement since pedestrians might be partially or completely blocked to the driver by the A-pillar as can be seen in fig. 9. The coefficient of the variable "H" exactly reminds the fact that left-turning vehicles can put pedestrians in a critical situation. Overall in this model, according to both coefficient of the variables "left-turn" and "H", these two different effects of this variable has been shown.

5. CONCLUSION

In this article, variables causing a conflict to be critical or dangerous were identified. As shown in table 1, mean vehicle and pedestrian speed led conflicts to a potentially dangerous situation. The TTC equation can clearly demonstrate an indirect relation between speed and TTC. Therefore speed alone can cause a potentially dangerous situation. Another variable which makes a conflict dangerous based on TTC is NoP (number of pedestrians). It suggests that pedestrians moving in groups need to be more cautious in their interaction with vehicles. The other variable which is a cause of the dangerous conflict is the direction of pedestrians. If the pedestrian movement is from left to right, the likelihood of the conflict being dangerous increases. Based on PET, it can be found whether a conflict is critical or not. Higher mean vehicle speed can make a critical situation for pedestrians engaged in an interaction with vehicles. Also, pedestrians interacting with left-turning vehicles are more likely to experience a critical conflict. According to both TTC and PET, NS, which represents pedestrians stopping more than other pedestrians, increases the likelihood of a conflict not being dangerous and critical. There are some variables that make a situation both critical and dangerous. The mean vehicle speed is one of them. The coefficient of this variable is negative in both models. The variable "NS" has a positive coefficient in both models. In their next project, the author of this paper will seek for the variables which make the conflicts critical and dangerous simultaneasly.

Fig. 9. The pedestrian which is blocked to the left-turning vehicle [43]

REFERENCES

1. WHO 2017, " Global status report on road safety: supporting a decade of action." Report.
2. Shin, H. S., Chen, G., & Holisko, G. (2011). Pedestrian safety programs in centers of large cities: Institutional settings and identified barriers. Transportation research record, 2264(1), 119-127.
3. Fu, T., Miranda-Moreno, L., & Saunier, N. (2018). A novel framework to evaluate pedestrian safety at non-signalized locations. Accident Analysis & Prevention, 111, 23-33.
4. Ni, Y., Wang, M., Sun, J., & Li, K. (2016). Evaluation of pedestrian safety at intersections: A theoretical framework based on pedestrian-vehicle interaction patterns. Accident Analysis & Prevention, 96, 118-129.
5. Iasmin, H., Kojima, A., & Kubota, H. (2015). Yielding behavior of left turning driver towards pedestrian/cyclist: Impact of intersection angle. Journal of the Eastern Asia Society for Transportation Studies, 11, 2146-2158.
6. Sander, U. (2017). Opportunities and limitations for intersection collision intervention—A study of real world 'left turn across path'accidents. Accident Analysis & Prevention, 99, 342-355.
7. Chisvert Perales, M. J., López-de-Cózar, E., & Ballestar Tarín, M. L. (2007). Quality and representativity of the traffic accident data in urban areas: State of the Art.
8. Amoros, E., Martin, J. L., & Laumon, B. (2006). Under-reporting of road crash casualties in France. Accident Analysis & Prevention, 38(4), 627-635.
9. Alsop, J., & Langley, J. (2001). Under-reporting of motor vehicle traffic crash victims in New Zealand. Accident Analysis & Prevention, 33(3), 353-359.
10. EC-European Commission. (2012). Commission staff working document on the implementation of national residue monitoring plans in the member states in 2009 (Council Directive 96/23/EC).
11. Loo, B. P., & Tsui, K. L. (2010). Bicycle crash casualties in a highly motorized city. Accident Analysis & Prevention, 42(6), 1902-1907.
12. Juhra, C., Wieskoetter, B., Chu, K., Trost, L., Weiss, U., Messerschmidt, M., ... & Raschke, M. (2012). Bicycle accidents–Do we only see the tip of the iceberg?: A prospective multi-centre study in a large German city combining medical and police data. Injury, 43(12), 2026-2034.
13. Austin, K. (1995). The identification of mistakes in road accident records: Part 2, casualty variables. Accident Analysis & Prevention, 27(2), 277-282.
14. Chung, Y., & Chang, I. (2015). How accurate is accident data in road safety research? An application of vehicle black box data regarding pedestrian-to-taxi accidents in Korea. Accident Analysis & Prevention, 84, 1-8.
15. Conche, F., & Tight, M. (2006). Use of CCTV to determine road accident factors in urban areas. Accident Analysis & Prevention, 38(6), 1197-1207.
16. Twisk, D. A. M., & Reurings, M. (2013). An epidemiological study of the risk of cycling in the dark: The role of visual perception, conspicuity and alcohol use. Accident Analysis & Prevention, 60, 134-140.
17. Dubos, N., Varin, B., & Bisson, O. (2016). A better knowledge of powered two wheelers accidents. Transportation research procedia, 14, 2274-2283.
18. Fu, T., Miranda-Moreno, L., & Saunier, N. (2016). Pedestrian crosswalk safety at nonsignalized crossings during nighttime: use of thermal video data and surrogate safety measures. Transportation research record, 2586(1), 90-99.
19. St-Aubin, P., Miranda-Moreno, L., & Saunier, N. (2013). An automated surrogate safety analysis at protected highway ramps using cross-sectional and before–after video data. Transportation Research Part C: Emerging Technologies, 36, 284-295.
20. Saunier, N., Sayed, T., & Ismail, K. (2010). Large-scale automated analysis of vehicle interactions and collisions. Transportation Research Record, 2147(1), 42-50.
21. Laureshyn, A., Svensson, Å., & Hydén, C. (2010). Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation. Accident Analysis & Prevention, 42(6), 1637-1646.
22. Hannah, C., Spasić, I., & Corcoran, P. (2018). A computational model of

pedestrian road safety: the long way round is the safe way home. Accident Analysis & Prevention, 121, 347-357.
23. Lee, J., Abdel-Aty, M., & Shah, I. (2018). Evaluation of surrogate measures for pedestrian trips at intersections and crash modeling. Accident Analysis & Prevention.
24. Almodfer, R., Xiong, S., Fang, Z., Kong, X., & Zheng, S. (2016). Quantitative analysis of lane-based pedestrian-vehicle conflict at a non-signalized marked crosswalk. Transportation research part F: traffic psychology and behaviour, 42, 468-478.
25. Lord, D. (1996). Analysis of pedestrian conflicts with left-turning traffic. Transportation Research Record, 1538(1), 61-67.
26. Akin, D., & Sisiopiku, V. P. (2007, January). Modeling Interactions Between Pedestrians and Turning Vehicles at Signalized Crosswalks Operating Under Combined Pedestrian–Vehicle Interval. In 86th Annual Meeting of the Transportation Research Board, Washington, DC.
27. Cheng, W., Zhang, N., Li, W., & Xi, J. (2014). Modeling and application of pedestrian safety conflict index at signalized intersections. Discrete Dynamics in Nature and Society, 2014.
28. Saulino, G., Persaud, B., & Bassani, M. (2015, January). Calibration and application of crash prediction models for safety assessment of roundabouts based on simulated conflicts. In Proceedings of the 94th Transportation Research Board (TRB) Annual Meeting, Washington, DC, USA (pp. 11-15).
29. Yagil, D. (2000). Beliefs, motives and situational factors related to pedestrians' self-reported behavior at signal-controlled crossings. Transportation Research Part F: Traffic Psychology and Behaviour, 3(1), 1-13.
30. Greenwald, M. J., & Boarnet, M. G. (2001). Built environment as determinant of walking behavior: Analyzing nonwork pedestrian travel in Portland, Oregon. Transportation research record, 1780(1), 33-41.
31. Kim, W., Kim, G. J., & Lee, D. (2016). Estimating potential conflicts between right-turn-on-red vehicles and pedestrians at crosswalks. International Journal of Urban Sciences, 20(2), 226-240.
32. Olszewski, P., Buttler, I., Czajewski, W., Dąbkowski, P., Kraśkiewicz, C., Szagała, P., & Zielińska, A. (2016). Pedestrian safety assessment with video analysis. Transportation research procedia, 14, 2044-2053.
33. Ismail, K., Sayed, T., & Saunier, N. (2010). Automated analysis of pedestrian–vehicle conflicts: Context for before-and-after studies. Transportation research record, 2198(1), 52-64.
34. Muley, D., Kharbeche, M., Alhajyaseen, W., & Al-Salem, M. (2017). Pedestrians' Crossing Behavior at Marked Crosswalks on Channelized Right-Turn Lanes at Intersections. Procedia computer science, 109, 233-240.
35. Andersen, C. S., Kamaluddin, N. A., Várhelyi, A., Madsen, T. K. O., & Møller, K. M. (2016). Review of current study methods for VRU safety: Appendix 7–Systematic literature review: Self-reported accidents.
36. Tageldin, A., & Sayed, T. (2016). Developing evasive action-based indicators for identifying pedestrian conflicts in less organized traffic environments. Journal of Advanced Transportation, 50(6), 1193-1208.
37. Kraay, J. H., van der Horst, A. R. A., & Oppe, S. (2013). Manual conflict observation technique DOCTOR (Dutch Objective Conflict Technique for Operation and Research).
38. Van der Horst, R., & Kraay, J. (1986, September). The Dutch Conflict Observation Technique–DOCTOR. In Proceedings of the workshop "Traffic Conflicts and Other Intermediate Measures in Safety Evaluation", Budapest, Hungary.
39. Mandrekar, J. N. (2010). Receiver operating characteristic curve in diagnostic test assessment. Journal of Thoracic Oncology, 5(9), 1315-1316.
40. Wu, J., Yan, X., & Radwan, E. (2016). Discrepancy analysis of driving performance of taxi drivers and non-professional drivers for red-light running violation and crash avoidance at intersections. Accident Analysis & Prevention, 91, 1-9.
41. Ren, G., Zhou, Z., Wang, W., Zhang, Y., & Wang, W. (2011). Crossing behaviors of pedestrians at signalized intersections: observational study and survey in China. Transportation research record, 2264(1), 65-73.
42. Peters, D., Kim, L., Zaman, R., Haas, G., Cheng, J., & Ahmed, S. (2015). Pedestrian Crossing Behavior at Signalized Intersections in New York City (No. 15-5975).
43. Why left-turns are so deadly://www.wnyc.org/story/left-turns/

HOW TO CITE THIS ARTICLE

M. Shafaati, A. M. Boroujerdian, Investigating the influential factors in changing the likelihood of involving pedestrians in dangerous situations, AUT J. Civil Eng., 4(3) (2020) 357-366.

DOI: 10.22060/ajce.2019.16486.5591