Pedestrian Gap Acceptance Logit Model in Unsignalized Crosswalks Conflict Zone

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Abstract:

Pedestrians are the most vulnerable road users. For evaluating and modifying pedestrian safety in unsignalized crosswalks, the first important issue is to identify and explore factors affecting the interaction behavior of pedestrians and vehicles in conflict areas. By analyzing those factors and determining how they affect road user's behavior, we can represent the plans and procedures to promote awareness and safety of both pedestrians and drivers. The goal of this article is to study pedestrian decision making behavior in unsignalized crosswalks and to determine factors affecting the crossing behavior in conflict areas. The supposed goal of this study was assessing how each factor can influence pedestrian-vehicle conflict behavior by means of developing logistic regression models. This work explores a variety of factors that may impact the gap acceptance behavior of pedestrian to provide a promising decision model. Discrete choice (probit) models of the gap acceptance decision are estimated from observations of pedestrians behavior when crossing at conflict zone.

Analysis results show that variables like vehicle speed change (VSC), pedestrian distance to vehicle lane (PDV), pedestrian age (PA) and vehicle position to the start point of pedestrian (Vp) are effective in Pedestrian gap Acceptance (PGA). Modeling decision making behavior by logit models, resulted in neglected R Square of 0.882 and correct classification of 94.9 pair wise cases. Area under ROC curve resulted in 0.98 that means the reliability of models is extracted. The results also showed that some variables like vehicle type (VT), waiting time (WT), number of pedestrians walking in a group (PN) and Gap or Lag are not effective in decision making logit models.

Keywords: Pedestrian, conflict zone, gap acceptance, logit models

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1. Introduction

Classifying countries according to the share of their traffic fatalities in their total deaths, Iran ranks sixth among 193 countries with a share of 7.1 percent [Scheottle and Sivak, 2014]. According to the latest World Health Organization (WHO) statistics for traffic fatalities, pedestrians, cyclists and motorcyclists have a share of 50 percent in all traffic fatalities in the world [Chan, 2013]. A quarter of fatalities (22 percent) are nearly pedestrians. Accordingly, studying various aspects of pedestrian movement has become one of the most important research topics in the highway and transportation engineering in the developed countries in recent years [IRTAD Report, 2013].

In May 2013, The Medical Emergency Response Center (MERC) reported that 28 percent of traffic fatalities in Iran had been pedestrians. However, as previously stated (see Figure 1), its global average is 22%.

Regarding the site of pedestrian-vehicle accidents and according to the pedestrian master plan in Tehran, accidents at intersections constitute a major part of pedestrian-vehicle accidents. The most common accidents in this category are due to crossing the road at high speed in such a way that at the moment of seeing pedestrian by driver, there isn't ample opportunity to stop the vehicle [Samiee et al, 2016]. In some cases, the driver wouldn't see the pedestrian just before the moment of collision.

Typically, providing pedestrian crossing facilities such as crosswalks, speed bumps, pedestrian bridges and pedestrian underpasses poses relatively high costs. Therefore, careful consideration of pedestrian-vehicle conflict behavior parameters in unsignalized crosswalks and proper implementation of pedestrian crossing facilities in order to increase their efficiency seems necessary. In this regard, the first step is to carefully identify factors affecting the crossing behavior in the conflict areas. Identifying pedestrian-vehicle conflict behavior and their mutual influence on each other, the factors affecting traffic safety are determined and the efficiency of pedestrian crossing facilities is increased. On the other hand, understanding the behavior of drivers in the conflict areas and possible reactions of pedestrians in these situations may result in better development and enforcement of traffic regulations in these areas. Furthermore, in order to provide technical and legal criteria with perfect efficiency, identifying the behavior of drivers in the conflict areas and possible reactions of pedestrians in these situations are essential. From the perspective of a traffic engineer, the most important applications of studying the factors affecting the road users' behavior and identifying their mutual reactions are careful scrutiny of models and exact simulation of conflict areas. This research is based on the pedestrian crossing behavior which affects the vehicles' behavior in the conflict zones. Among regression models, logistic regression, or logit model, provides a convenient closed form for underlying choice probabilities without any requirement of multivariate integration. In other words, logistic regression measures the relationship between the categorical dependent variable and one or more independent variables by estimating probabilities using a logistic function, which is the cumulative logistic distribution. Logistic regression can be binomial, ordinal or multinomial. In the current research binomial regression was employed. Accordingly, binomial or binary logistic regression deals with situations in which the observed outcome for a dependent variable can have only two possible types (e.g. "dead" vs. "alive" or "acceptance" vs. "rejection"). The gap acceptance issue is fundamental to traffic engineers, and therefore the fit of the model to pedestrians' behavior is of an essence. In the current research- by employing logit model, gap acceptance in unsignalized crosswalks conflict zones was further developed.

2. Literature Review

Among the studies that investigate different aspects of a pedestrian movement as a way of transportation and/or its impact on the traffic flow, almost all of them have introduced the pedestrian as a major criterion in analyzing safety, and traffic flow modeling and assessment [Tanariboon and Guyano, 2010]. When a pedestrian crosses a street, necessary decisions for gap acceptance are to be made. Pedestrian decision making in these cases leads to acceptance or rejection of the gap. In a normal process of crossing, the available gap is the gap for the pedestrian to cross. If a pedestrian accepts the gap for crossing, the gap is called the accepted gap and otherwise it is called the rejected gap. The proper gap for a crosswalk is determined by dividing the crossing distance by the walking speed and then adding the outcome to the start-up time [Várhelyi, 1996]. The gaps are generally defined in two types of Gap and Lag. Lag is the distance between a vehicle and a pedestrian at the time of crossing (the time when a pedestrian arrives at the crosswalk) while Gap is the distance between two successive cars allowing a pedestrian to pass a crosswalk. Since it is possible when a pedestrian wants to cross a multi-lane street, there wouldn't be a proper gap for the pedestrian to cross all the lanes. Thus, the behavioral pattern of pedestrians in high traffic volume and multi-lane approaches deploys a rolling-gap. This means that pedestrians cross a multi-lane street in such a way that for every line they use the gap of its own [Zhao, 2012].

In 2010, in a research project conducted by Kuan-min et al, the issue of pedestrian gap acceptance in unsignalized intersections when facing a group of vehicles was discussed. The study had been conducted with the major goal of pedestrian delay estimation in high traffic volume intersections. First, the China's crosswalks were classified into six levels of service based on the pedestrians comfort level, their safety and psychological limits (thresholds) such as acceptable delay. Then, the pedestrian delay analysis was performed [Kuan-min et al, 2010]. In another study conducted by Zeng et al, they presented a simulation model for movement of pedestrians crossing a signalized intersection with the goal of evaluating the pedestrian safety. In their study, the mathematical modeling was focused. They used video recorded data but there was no exact explanation of the way the information was extracted from the video. Their analysis showed that the direction of movement of a pedestrian depended on the geometry of the intersection, the origin and the destination, the location of passengers at any moment and the density of other road users [Zeng et al, 2013]. In 2012, Gao et al conducted one of the newest studies in this field. They identified four types of traffic conflict and they also presented three analytical models in order to estimate delay based on the identified patterns. The type of pedestrian–vehicle conflict was the most significant parameter studied in their study. Two types of conflict including conflict from the right and conflict from the left were defined based on the line in which the pedestrian encountered a vehicle. In studies carried by Oxley et al, Lobjois et al, some other parameters such as age, police presence and other pedestrians' behavior were investigated as the factors influencing the pedestrian gap acceptance [Oxley et al, 2005]. Accepting bigger gaps by aged pedestrians in comparison with the younger ones has been due to their different walking speeds. Yannis, 2010, in his studies found that pedestrian gap acceptance was more depended on the longitudinal distance from vehicle to pedestrian, the vehicle length, the presence of illegally parked cars and pedestrian gender. B. Raghuram Kadali and Vedagiri Perumal, in their studies on the gap acceptance in Hyderabad, India, considered some parameters such as pedestrian gender, pedestrian age, vehicle speed, pedestrian speed and pedestrian direction in acceptance of a proper gap. Their results showed that pedestrian gap acceptance in Hyderabad was depended on pedestrian speed, vehicle speed, pedestrian direction, rolling gap and the age of the pedestrians [Kadali and Perumal, 2013]. Some of the researchers like Li et al, 2011, investigated the impact of intelligent systems for traffic control on the pedestrian and vehicle delay. Lane width, number of lanes, pedestrian average walking speed, vehicle traffic volume, pedestrian traffic volume and the distance of the installed intelligent system for traffic control to the intersection were considered as the effective parameters in their study [ZENG, 2013]. According to the results of a study conducted for Federal Highway Administration (FHWA) by Palamarty et al, 1994, pedestrians cross streets with less caution when they are facing turning movements of vehicles. It was found that the traffic flow of adjacent vehicles in comparison with the traffic flow of distant vehicles had more impact on the pedestrian gap acceptance. They also noticed that the impact of walking in groups was significant in pedestrian behavior [Palamarthy, Mahmassani and Machemehl, 1996].

Reviewing the literature in the field of pedestrian decision making and investigating the studies conducted on the vehicle-pedestrian behavioral models in the conflict areas, it is evident that different variables have been investigated in different studies and they have been introduced as the effective factors in the models. The diversity of the results of previous studies shows that the behavior of pedestrians and vehicles may be changed by the native environment and the social norms in any society. Given that there isn't any study conducted on modeling the pedestrian behavior in unsignalized crosswalks in the country, there's a need for a research in this field in order to allow a comparison with results from other countries and developing criteria and standards for pedestrian safety [seyyed Abrishami et al, 2014]. In the current study, the variables affecting pedestrian decision making in an unsignalized crosswalk have been investigated.

3. Methodology

By studying the literature, it was found that in different studies, various tools have been used for field data acquisition and data entry in order to perform an analysis. In order to collect data on pedestrian behavior in the case studies, some techniques including using laser speed gun, using traffic-counting devices, filming the conflict zones and using the measuring equipment in the vehicle have been applied. In the acquired data entry level and before performing the statistical analysis and modeling, manual methods (observations taken by a human operator) and mechanical methods (Using image processing software) have been applied. The data acquisition process in this study has been conducted in two stages which are discussed in detail. The raw data has been collected in the field by filming and the users' behavioral parameters in the conflicting movement have been extracted using image processing software. Figure 1 shows the case study location. Numerous stops of the vehicles due to heavy traffic of the north-south approach made the possibility of investigating the pedestrian-vehicle mutual behavior in the conflict zone impossible. Therefore, the pedestrian movements in the south-north approach and at the crosswalk have been focused.

The required information for performing the analysis was obtained from an image processing software called Tracker. Based on the literature, 16 parameters related to pedestrian-vehicle conflict were taken as the necessary variables for modeling. These variables include: the vehicle average speed, the pedestrian average speed, pedestrian speed change, pedestrian direction change, vehicle behavior change, pedestrian to vehicle distance, length of the gap, acceptable waiting time, pedestrian gender, pedestrian age, group movement, vehicle location, pedestrian start point, type of pedestrian cross-movement, vehicle type and type of the gap (Gap or Lag). Extracting the required data for the analysis, the information was entered to the spreadsheet software, Excel, in order to be integrated and sorted. Then using software, IBM SPSS Statistics 20, the statistical analysis was performed. Pedestrian gap acceptance and vehicle gap acceptance are defined as a decision making process in order to accept or reject a gap of particular length.

In this case, the gap azcceptance model would be a discrete choice model. In the current study logit model was deployed. After performing preliminary statistical analysis, the correlation between the variables were determined and the logistic regression model (in Forward Stepwise way) was used to determine the factors influencing pedestrian decision making. There are 158 conflict observations in this study in order to perform

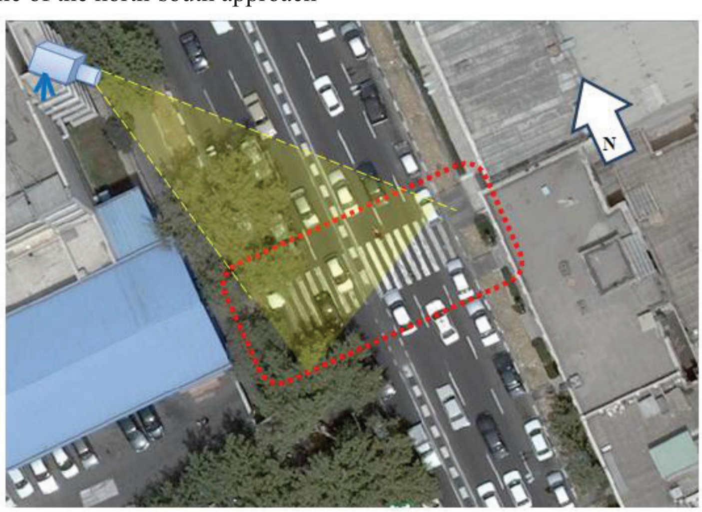

Figure 1. The case study location

statistical analysis and build the model. In the literature, not all specific equations are mentioned [Peng et al, 2002]. Although a minimum ratio of 10 observations per one independent variable in the model has been suggested in many researches [Tabachnick and Fidell, 2001 - Peng and So, 2002].

4. Results and Discussion

158 conflicting movements were investigated at the crosswalk. The descriptive statistics and characteristics of observations according to the evaluated criteria are expressed. More recognition of the observations is obtained and the initial assumptions about the pedestrian decision making and the parameters affecting it are formed by investigating the general characteristics of the movements. Table 1 gives an overview of the number of observations made for each variable along with the values of the minimum, maximum, average, standard deviation and the variance of all variables.

Table 1. Descriptive statistics of the variables

During the observed period, 49 percent of the conflicting movements were done by pedestrian gap acceptance. In 22 percent of the cases, the pedestrian has moved as a group (two or more). Among all the observed pedestrian decision making (acceptance or rejection of the gap), in 59 percent of the cases, the vehicle was in the first line (the line which is closer to the pedestrian) and in 41 percent of the cases, the vehicle had been at a greater distance (the second or the third line). On the other hand, 82 percent of all the cross traffic has been a gradual crossing (line by line). Therefore, a very small number of movements have been done with a stop at the edge of the street due to the existence of vehicles on the second and third lines. The average waiting time of pedestrians (at the beginning of crossing) was calculated 1.09 seconds. The average gap length was calculated 1.5 seconds in the rejected gaps and 3.28 seconds in the accepted gaps. On the whole, 63 percent of the gaps were classified as GAP and 37 percent of them were classified as LAG. Separately, 60 percent of the accepted gaps and 65 percent of the rejected gaps were classified as GAP.

One of the variables affecting the pedestrian decision making is the vehicle speed in the conflict zone. To change the vehicle behavior (speed and line), the pedestrian speed can be effective as well. Table 2 gives the average values for the road user speed in the conflict zone for the accepted and rejected gaps, separately. According to this table, it can be seen that the pedestrian's average speed in the accepted gaps is more than the pedestrian's average speed in the rejected gaps. The result indicates the possibility of direct relationship of the pedestrian speed with the gap acceptance. Moreover, more average speed of the vehicle at the rejected gaps shows a possible inverse relationship between the vehicle speed and the pedestrian gap acceptance.

Table 1. Descriptive statistics of the variables

Variable	Number of observations	Minimum	Maximum	Average	Standard deviation	Variance
AoR	158	0	1	0.4937	0.501	0.252
GL	158	0.5	6.3	2.3747	1.235	1.526
LoG	158	0	1	0.6266	0.485	0.235
PA	158	0	2	0.5633	0.681	0.464
PDV	158	0	5.2	1.1763	1.066	1.137
PG	158	0	1	0.6456	0.479	0.230
PN	158	0	2	0.2785	0.563	0.317
Pp	158	0	1	0.6709	0.431	0.222
PPC	158	0	1	0.1456	0.354	0.125
PS	158	0.5	3.2	1.2774	0.427	0.183
PSC	158	0	1	0.0949	0.294	0.086
RG	158	0	1	0.8228	0.383	0.147
VDP	114	2	17.5	10.3504	3.723	13.93
Vp	158	1	3	1.4434	0.569	0.325
VS	158	1.4	13.3	6.6089	4.784	7.754
VSC	158	0	1	0.2975	0.458	0.210
VT	158	0	2	1.0633	0.351	0.123
WT	158	0	10.4	1.0905	1.809	3.276

Table 2. Pedestrian's average speed and vehicle's average speed for both the accepted and rejected gaps

Average speed (m/sec)	Vehicle	Pedestrian
Accepted gap	5.8	1.42
Rejected gap	7.39	1.14

An estimation of the pedestrian's critical gap when crossing the street may be reached by drawing the distribution of the accepted and rejected gaps.

In statistical modeling, the Logit model is built by the logistic regression. The developed model with the use of IBM SPSS Statistics 20 software is presented and the results of the significance test and goodness of fit of each model are expressed as well.

In 44 observations VDP factor due to limitation of camera vision was incalculable. In this regard, in the first step, VDP factor was bypassed. Moreover, PPC and PSC factors due to lack of logical interconnection with pedestrian gap acceptance were bypassed as well. In the other words, PPS and PSC, in the conflict zone, take leading part in the vehicle decision not pedestrian. Accordingly, final pedestrian gap acceptance model was developed with remarkable precision (NR Square=0.882). It should also be noticed that, by applying this model, pedestrians' decision were prognosticated a 94.9% accuracy. Tables 3 and 5 show the accuracy, the anticipation and the variables in the final model.

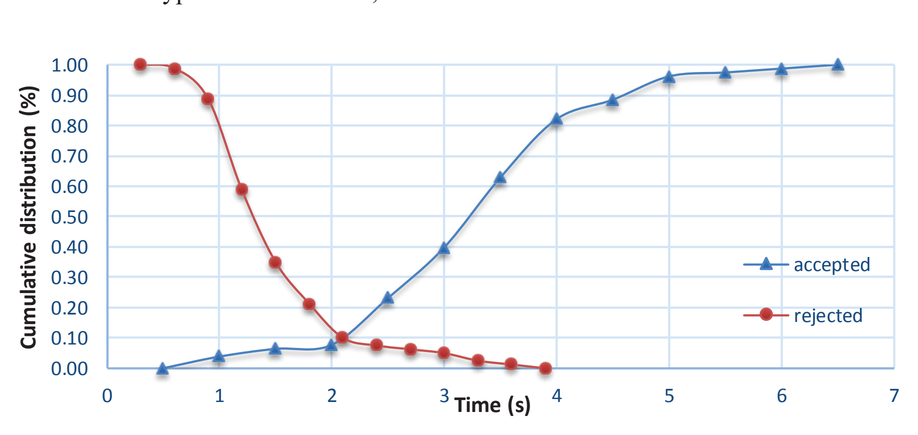

Figure 2. Graphical method for determining the critical gap

Table 3. Predictive power of the model

-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
47.973	0.661	0.882

Table 4. Predicted values assessment by the model

Observation \ Prediction	Gap rejection	Gap acceptance	Accurate estimation of the model (%)
Gap rejection	75	5	93.8
Gap acceptance	3	75	96.2
Average value for the Accurate estimation of the model (%)	-	-	94.9

Table 5. Final variables entered to the model

Variables	B	S.E.	Wald	Df	Sig.	Exp(B)
PS	4.351	1.502	8.393	1	0.004	77.576
VSC	3.287	1.066	9.502	1	0.002	29.768
PDV	1.224	0.444	7.611	1	0.006	0.294
Vp	2.436	0.955	6.501	1	0.011	11.428
GL	2.899	0.643	20.338	1	0	18.149
Constant	15.459	3.848	16.143	1	0	0

Table 6 gives an overview of the effect of adding any of the variables to the model on the independent variable and shows the effect of entering any of the variables on improving the model classification as well.

According to table 5, the pedestrian gap acceptance is defined as equation 1. The goodness of fit of the model results are given in table 7. The result of the significance test, being more than 0.05, shows the confirmation of the null hypothesis representing that there is no difference in the predicted an observed values. Therefore, the proper fitness of the model to the observations is confirmed in this test.

$$\ln(p/(1-p))=-15.459+2.899(GL)+2.436(Vp)-1.224(PDV)+3.287(VSC)+4.351(PS) \quad (1)$$

In order to check the proper fitness of the model to the observed data, Hosmer and Lemeshow Test has been used. In the output of this method, the result of the significance test being more than 0.05 shows the confirmation of the null hypothesis representing that there is no difference in the predicted an observed values. Accordingly, it can be seen that proper fitness of the model to the observations is confirmed in this model. In order to determine the validity of the obtained model, the ROC curve was used. The curve gives values between 0.5 and 1. Where 0.5 shows that the model predictions are accidental and 1 shows that the model considers a higher probability for the accurate ones than the inaccurate ones (for binary dependent variables, 0 and 1). Figure 3 and table 8 illustrate the ROC curve. The area under the curve resulted in 0.985 for the model which shows the validity of the model. The results show that the prediction of the model is not accidental and a proper validity is identified for it.

5. Sensitivity Analysis

Generally, investigating the changes in the logistic regression is used as one of the methods for sensitivity analysis of functions with respect to the changes in the variables. Therefore, assuming the average value (based on the acquired descriptive statistics) for continuous variables, for each of the discrete variable conditions in the model, the changes in likelihood function can be calculated according to the change in one of the variables. Therefore, at any stage, one of the values for

Table 6. Effect of variables entered to the model in each step

Variable	Correct Class %	Final model in each step			Improvement of the model		
		Sig.	Df	Chi-square	Sig.	df	Chi-square
IN: GL	88.6	0	1	111.162	0	1	**111.162**
IN: VSC	86.1	0	2	135.609	0	1	**24.447**
IN: PS	91.1	0	3	150.24	0	1	**14.631**
IN: PDV	91.1	0	4	161.975	0.001	1	**11.735**
IN: Vp	94.9	0	5	171.036	0.003	1	**9.061**

Table 7. Goodness of fit test results

Chi-square	Df	Sig.
5.908	8	0.658

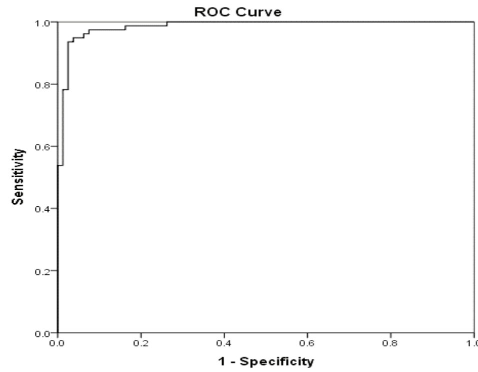

Figure 3. ROC curve for determining the validity of the model

Table 8. Area under the ROC curve for the model

Area	Std. Error	Asymptotic Sig.	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
0.985	0.0008	0	0.97	1

the discrete variables is considered and the changes in the probability of the Logit function are calculated with respect to the changes in one of the continuous variables (assuming the average value for other continuous variables). Figure 4 illustrates the pedestrian gap acceptance versus pedestrian's average speed for each of the scenarios for the line in which the vehicle is moving in, as there is a change or no change in its speed. It is assumed that the gap is constant and has a value of 2.2 seconds (an average value and close to the critical value).

Figure 4 expresses that the probability of gap acceptance at a fixed interval is increased by change (reduction) in vehicle speed in the conflict zone. The changes in the pedestrian gap acceptance with respect to the changes in the observed variables for the length of the gap are illustrated in figure 5. In summary, Figure 5 shows the increase in the probability of gap acceptance with the increase in the length of the gap. In case of a change (reduction) in the vehicle speed, the probability of the gap acceptance is increased as well. The curve also illustrates that when there is a pedestrian-vehicle conflict in the second line (with respect to pedestrian start point), pedestrian gap acceptance (at the same time) has a higher probability.

6. Conclusions

This study has been conducted base on identifying pedestrian crossing behavior and the characteristics of vehicle movement in the conflict zone affect the pedestrian gap acceptance and providing a pedestrian

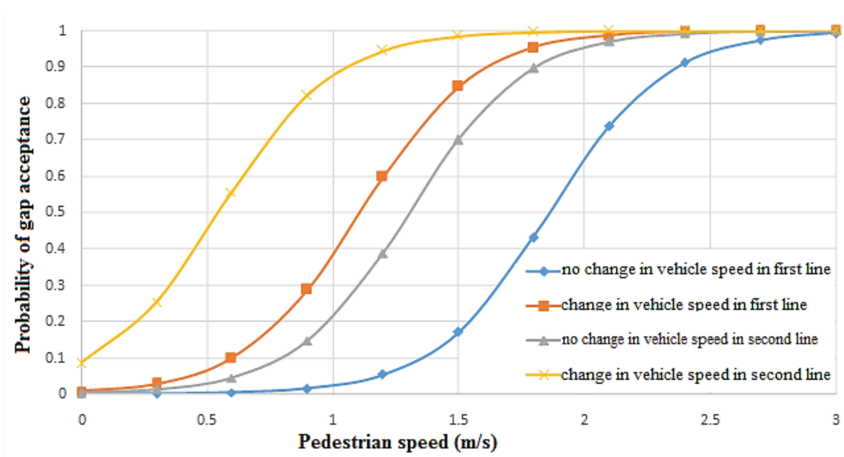

Figure 4. The probability of pedestrian gap acceptance versus pedestrian's average speed

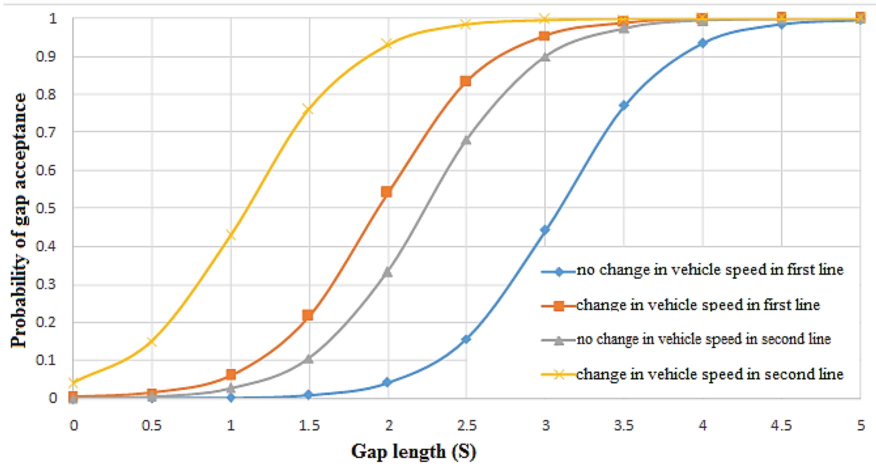

Figure 5. The probability of pedestrian gap acceptance versus the length of the gap

gap acceptance Logit model in unsignalized crosswalks conflict zone. Field data was acquired by filming at the crosswalk. Identifying the probability variables affecting the model and using an image processing software, 156 pedestrian-vehicle conflict observations were made. The fitted model to the observations showed that "pedestrian speed", "vehicle speed change ", "length of the gap", "vehicle location" and pedestrian distance to vehicle lane (PDV) are the variables affecting the pedestrian decision making to accept or reject a gap. Among 16 variables for the pedestrian and the vehicle in the conflict zone, vehicle type (VT), pedestrian start point (PP), GAP or LAG (LoG), Number of pedestrians walking in group (PN), pedestrian gender, waiting time (WT) were not effective in any of the built decision making Logit models.

Based on the achieved results from the performed analysis, the changes in the vehicle speed, pedestrian distance to vehicle lane, pedestrian speed, vehicle location and the length of the gap are affecting the pedestrian gap acceptance model. The accuracy of the model (based on N R square) is 0.882 and it resulted in the correct classification of 94.9. Drawing the ROC curve, the area under the curve resulted in 0.98 which verifies the validity of the model. The sensitivity analysis of the model was performed to the changes in any of the continuous variables with respect to different modes of the discrete variables. The results of this study can be used in computational simulations and development of the behavioral models predicting movements in order to enhance the transportation safety in the conflict zones.

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