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Evaluating Pedestrian Safety at Unprotected Mid-Block Crossings Under Mixed Traffic Conditions

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Abstract: This paper investigates pedestrian safety at urban mid-block crosswalks under mixed traffic conditions using pedestrian safety margin (PSM) as a surrogate safety measure (SSM). To comprehend the objective, video-graphic surveys were carried out at nine uncontrolled mid-blocks crosswalks having varying roadway, demographic, traffic and pedestrian characteristics. Pedestrian safety margin (PSM) values, which is a difference between accepted gap and crossing speed were extracted manually from the recorded video to quantify pedestrian safety at urban uncontrolled midblock crosswalks. Both negative and positive PSM values were obtained. Negative PSM values indicate higher risks compared to positive PSM values. A multiple regression model was then developed to examine the effect of different variables on PSM values. It was found that vehicle gap, pedestrian speed, vehicle speed, rolling behaviour, geometrical condition of roadway had significant effect on PSM values. Other significant variables included illegal parking, presence of markings, and number of lanes.

Keywords: Mid-block crossing, Pedestrian safety, Pedestrian safety margin (PSM), Regression

1. INTRODUCTION

Safety on road is of the utmost priority for any country as it has significant effect on both nation's economy and people's welfare. Generally, lane discipline is violated in Indian driving context. Further, poor yielding and compliance by both pedestrians and drivers to set traffic rules has resulted into millions of accidents every year. In urban areas, mainly accidents or crashes occur at unprotected midblock locations. Crosswalks are the most essential and frequently used transport facility by pedestrians to cross the road on the other side to reach their destination. Pedestrian crossing behaviour is mainly governed by the gap acceptance theory. Each pedestrian has a critical gap to cross the street. Many researches correlate the minimum gap from the vehicle, which is accepted by pedestrians who intend to cross streets at mid-block with traffic, pedestrian and demographic factors. In most of these researches

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(Oxley et al., 2005; Das et al., 2005) the distance between the vehicles and the pedestrians appears to influence the minimum gap accepted by pedestrians. In addition, an increase in traffic density leads to smaller accepted gaps. These gaps are often described by means of probability distributions or are estimated by means of linear regression modelling. Indicatively, it can be mentioned that the minimum accepted gap has been estimated at two seconds and the mean accepted gap at eight seconds (Das et al., 2005).

Behavioural analysis has revealed that pedestrians prefer rolling gap (pedestrian roll over the small vehicular gaps) instead of waiting for larger gaps to cross the road (Brewer et al., 2006; Kadali and Vedagiri, 2013). With heterogeneous nature of traffic on Indian roads, pedestrian-vehicle interaction becomes complex. Further, poor yielding behavior and compliance behavior by both pedestrian and vehicle driver, further aggravates the situation and as a result, both pedestrians and vehicle drivers endure more risk. Pedestrians are vulnerable road users and are significantly over-represented in road traffic crashes. While improving transportation facilities such as flyovers and widening of roads, for motorized vehicle users, pedestrian facilities are overlooked. Lack of exclusive facility for pedestrian crossing in Indian condition has often led to fatal accidents. The pedestrian and bicycle fatalities in India is 27.4% (MORTH, 2010) and most of the pedestrian fatalities (85%) are observed at midblock locations (Mohan et al, 2009) and 54% pedestrian accidents are related to road crossing (Kumar and Parida, 2011). Statistical report by the ministry of urban Development (MOUD) found that 19% of the pedestrians were accused in road accidents (MOUD, 2008). Some studies have found that 8.3% of fatal pedestrian accidents in India occur in road accidents at mid-block crosswalks (NCRB, 2013), and global studies show that over the last two decades, the number of pedestrian related road crashes have risen drastically in non-intersection locations where pedestrian trips are more than other modes of transportation (NHSTA, 2015). Studies have shown that the number of pedestrian collisions is more in developing countries as compared to the developed countries (Asiamh et al 2002; Peden et al 2004). A maximum number of past studies indicate that human component of both pedestrians and motorists are the most influential factors corresponding to pedestrian crashes. Past studies shows a number of factors that have an effect on pedestrian crossing behaviour, these factors include road user variables demographic (e.g., gender, age), approaching vehicular characteristics, presence of illegal parking, roadway characteristics (e.g., road width, presence of marking, width of median, traffic controls), situational factors (e.g., group size, traffic volume, distraction) and environmental factors (e.g., time, weather conditions). While crossing the road, the pedestrian's decision to cross the section is governed by the gap available. In this process, the pedestrian may be successful or unsuccessful and it depends on the available vehicular gaps, yielding behaviour of a driver and pedestrians' tactics, how pedestrian yield by changing path, reducing the speed to avoid the conflict. When adequate gap is not available pedestrians rolls over the small vehicular gaps in each lane to accept the small vehicular gaps by adjusting the crossing speed in order to reduce overall waiting time, which is characterized as rolling behaviour (Brewer et al., 2006; Kadali and Vedagiri, 2013). Such rolling behavior is considered to more severe and significant safety implications.

The pedestrian safety can be assessed by means of pedestrian gap acceptance behaviour and vehicular gaps with effect of different pedestrian behavioural characteristics (rolling behaviour, increase in speed). The evaluation of pedestrian safety under heterogeneous traffic conditions (statics and dynamics characteristics of vehicles) is a multifaceted issue. Pedestrian safety can be assessed by either using historical crash data or proactive (non-crash) measurements. Traffic safety is commonly analyzed in terms of the number of traffic crashes and human losses. This approach is regarded as 'reactive', implying that a significant number of accidents must be recorded before a decision can be made. One of the most draw back with this approach are concerns regarding the quality and availability of past accident data with police department for the given location. This has led to transfer of interest towards the surrogate measures that reflect the safety of a road facility. The surrogate measurement technique should satisfy two conditions, first a measurable or observable non-crash event that is physically related in a predictable and reliable way to actual crashes, and a practical method for converting or calibrating the non-crash event into the corresponding crash frequency and/or severity. In this context, the safety margin method is one of the proactive techniques to evaluate pedestrian safety at crosswalk locations. Safety margin value is the safe time gap maintained by pedestrian while accepting an approaching vehicle gap to cross the road. The pedestrian safety margin (PSM) can be defined as, the time difference between the accepted vehicular time gap and pedestrian actual crossing time (Oxley et al., 2005; Lobjois and Cavallo, 2007). The decrease in safety margin will result in an increase in pedestrian-vehicle interaction and therefore, increases the conflict with vehicles (Kadali et al., 2016). Increased number of pedestrian-vehicle conflict at mid blocks on urban road has motivated authors to study the pedestrian safety at unprotected mid-block crosswalks under mixed traffic conditions. The objective of the present study has been formulated to evaluate pedestrian safety at uncontrolled mid-block crosswalks with varying roadway, demographic and traffic flow characteristics under mix traffic conditions prevailing in countries like India.

2. LITERATURE REVIEW

After review the past literature it has been found that significant number of studies have been carried out to evaluate the pedestrian safety either by crash based methods (historical crash data) and another user opinion surveys or proactive (non-crash) based methods (Retting et al, Holland and Hill, 2007; Ukkusuri et al., 2012). One of the most often studied aspect in the pedestrian safety analysis is identifying the significant factors affecting the safety of pedestrians, either by historic crash-based method (Sinha and Sengupta, 1989; Zegeer et al., 1993) or conflict method (Svensson and Hydén, 2006; Lobjois and Cavallo, 2007). Studies have shown the effect of pedestrian age and gender on pedestrian safety analysis at the intersection and mid-block crosswalk locations (Oxley et al., 2005; Lobjois and Cavallo, 2007, 2009). Another study has shown that the type of approaching vehicle also has a significant effect on pedestrian safety (Zajac and Ivan, 2003; Liu and Li, 2009). However, some studies have stated that approaching vehicle distance is more important as compared to the pedestrian individual characteristics in decision-making process of road crossing (Connelly et al., 1998, Yannis et al., 2013). Further, the driver’s yielding behaviour is also one of the important factors contributing to pedestrian safety at mid-block crosswalk location. Some studies identified that there is no significant effect of static sign boards, traffic calming devices, and markings on the driver’s yielding behaviour at crosswalks (Huang and Cynecki, 2000; Knoblauch et al., 2001). Effect of vehicle type on pedestrian safety is also investigated and it was found that light vehicles more dangerous than heavy vehicles (Lefler and Gabler, 2004). Research studies have shown that with an increase in the driving speed, there is a decrease in driver yield to pedestrians (Salamati et al., 2013). Further, research studies have been done with different modelling techniques in order to identify the factors contributing to the driver yield behaviour at un-signalized crosswalks. The results showed that the behaviour of pedestrians has a strong correlation with the driver yield behaviour (Kadali and Vedagiri, 2013). Further, past studies show that the pedestrians walking in groups bear lesser risk than individual pedestrian during road crossing (Harrell, 1991). Past research found that the increase in vehicle gap size increases the safety margin value (van der Molen, 1981; Kadali and Vedagiri, 2016). Studies have also been conducted to understand the effect of pedestrian looking behaviour on the PSM while crossing the road (Schoon, 2006; Zhuang and Wu, 2012).

Some studies reported that pedestrians' minimum PSM value while crossing the road depends on the vehicular gap size, pedestrian speed, age and rolling gap and PSM is dynamically associated with the pedestrian rolling gap condition and pedestrian speed in developing country like India (Kadali et al. 2016). Recent studies have been conducted to understand the effect pedestrian behavioural characteristics such as path change, speed change, concentration towards vehicular gap, rolling behaviour on PSM value as well as the probability of PVNC behaviour with an approaching vehicle, type of vehicle while crossing the road. (Kadali et al. 2016). Some studies found that the accepted gaps depend on the distance from the incoming vehicle, size of vehicle, presence of illegal parking, gender of the pedestrian. In addition, sensitivity of the gaps accepted to the distance from the incoming vehicle increases as the size of the vehicle increases and when illegally parked vehicles are present in the area (Yannis et al., 2013).

Most of the above studies are related to well-designed crosswalks present in developed countries, where in the pedestrian-vehicle interaction might be less. In contrast, the mixed traffic conditions in developing countries, where the traffic is highly heterogeneous, non-lane based and with a wide variety of pedestrian behaviour as well as vehicle characteristics, results in higher pedestrian-vehicle interaction. Recent study on safety margin was carried out on 2-lane undivided, 4-lane, 6-lane divided roadway in single city; Mumbai (Kadali et al., 2016) and therefore, change in culture is not incorporated. In this context, the present study evaluates the pedestrian safety by using proactive safety measurements at nine different unprotected mid-block crosswalks under mixed traffic conditions from different cities from northern (Delhi, Chandigarh) part and western (Mumbai, Surat, Ahmadabad) part of the country having diverse culture and pedestrian behaviour. Factors affecting pedestrian safety margin values are identified by developing multiple linear regression model. In addition, elasticity analysis is also performed to explicitly quantify the effect each of the pedestrian characteristics, vehicular characteristics, and geometric condition on the pedestrian safety margin values. Further, sensitivity analysis was carried out to comprehend the effect of pedestrian characteristics, vehicular characteristics and geometric condition of roadway on pedestrian safety margin values.

3. DATA COLLECTION AND METHODOLOGY

To evaluate pedestrian safety, nine unprotected mid-block crosswalk locations having varying roadway characteristics such as number of lanes (roadway width), median width and the median open width, presence of marking are selected from the northern and western part of the country. In the western part Mumbai, Surat, Ahmadabad city and from the northern parts are Dwarka, Chandigarh, having diversified culture, life style and working environment were selected. The subject study locations has significant difference in pedestrian, traffic flow and land-use characteristics. The snapshots of selected location are as shown in Figure 1. During the video graphic survey, for the selected study locations significant pedestrian-vehicle interactions with varying magnitude are observed.

Location-I (Vakola, Mumbai)	**Location-II (Ramprashtha Delhi)**	**Location-III (Varacha, Surat)**	**Location-IV (Dwarka ,Sec 6-10 ,Delhi)**

Location-V (Vile Parle, Mumbai)	**Location-VI (Bandra, Mumbai)**	**Location-VII (Neelam Cinema Chandigarh)**	**Location-VIII (Ashdodia Ahmadabad)**	**Location-IX (ISBT Chandigarh)**

Figure 1. Study Site locations

To capture naturlistic pedestrian-vehicle interaction data, videography was conducted in the months of June 2015, October 2015 and 25 November 2015 for the subject study locations during normal working day under ideal weather conditions. Data was recorded by wide angle high digital video camera (frame rate: 29 frames per second; 55X zoom) was mounted at vantage point at the multi-storied building in such a way that it records movement of pedestrian and vehicle as well. One video camera was used for capturing the pedestrian behavioural characteristics data and the other were utilized for capturing the vehicular characteristics. Video recording was started morning 8.00 A.M. to 6.00 P.M. on working days at each of the selected location.

The video filmed data was extracted with the help of AVS video editor software, where 1s data was divided into 33 frames with the help of AVS video editor software. The traffic (safety margin and vehicular gap) data was extracted with an accuracy of 33 milliseconds (30 frames per second, i.e., 0.033s) by clicking a step forward option of the video extraction software. The pedestrian individual characteristics comprising of gender and age were collected based on visual appearance. Pedestrian waiting time at kerb, behaviour at kerb, accepted vehicular gap sizes (time gap) while crossing as well as actual crossing time depending on the pedestrian behavioural of each individual crossing path were extracted from the video data. Vehicle speeds were calculated by extracting the time to cover a trap known length of 30m marked on the road with white paint. Pedestrian speeds were calculated from the extracted time to cover the crosswalk length.

4. PEDESTRIAN SAFETY MARGIN (PSM)

Pedestrian safety margin (PSM) is defined as the time difference between accepted vehicular time gap (corresponding to the pedestrian crossing path) and pedestrian actual crossing time (based on the field condition and pedestrian behaviour) (Kadali et al, 2016, Oxley et al., 2005; Lobjois and Cavallo, 2009). Figure 2 illustrates pedestrian crossing behavior.

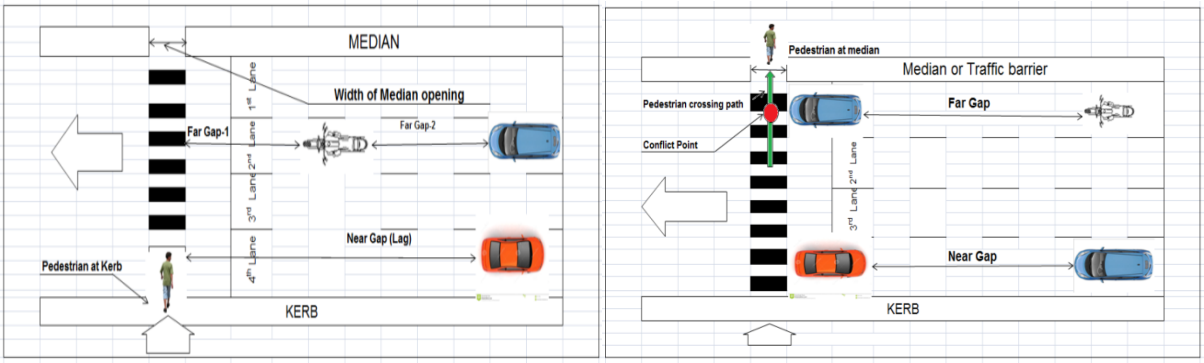

Figure 2. Pedestrian maneuvering during crossing at different vehicle gaps

During the interaction between the pedestrian and approaching vehicle while crossing the road, the pedestrian safety margin value can be positive or negative. Positive values of safety margin can be attributed to availability of larger accepted gap size or higher pedestrian speed to reach the median resulting into lower crossing time. Values of PSM nearer to zero or negative are more critical compared to positive values. Therefore, the positive (or) negative value of PSM would mainly depends on the road user behaviour either pedestrian (or) vehicular driver (Kadali et al., 2016).

4.1 Post Hoc Test on the Extracted Data

In order to find out significant difference in PSM values based on location, multiple comparison using Post Hoc technique (Student-Newman-Keuls) was carried out and the results are summarized in Table 1. Post-Hoc test was performed with a sole motive to bifurcate data for modelling and validation. Data with insignificant differences was considered as one set of data, which was used either for modelling or for validation.

Table 1. POST HOC Test Result

Coding for Test			**POST HOC (Student-Newman-Keuls) Test Result**				
Location No	Code	Test	Code	N	Subset for alpha = 0.05		
					1	2	3
I	00	Student-Newman-Keuls	7.00	1097	0.8895		
II	01		6.00	0744			2.0784
III	02		2.00	2826			2.0830
IV	03		5.00	2913			2.2084
V	04		1.00	0276			2.2341
VI	05		4.00	2009			2.2479
VII	06		3.00	0703			2.3189
VIII	07		0.00	1286			2.3618
IX	08		8.00	1811		1.723	
			Sig.		1.000	1.00	0.068

From the result (Table 1), it can be concluded that the mean value of safety margin for location-VIII and IX differ from all other locations. Therefore, the extracted data of location I-VII were used for model formation and the extracted data of location VIII and IX were used for validating the model.

4.2 Significance of Collected Variables on PSM

Descriptive statistics of variables influencing PSM is summarized in Table 2. The variables were identified based on past literatures. Further, Analysis of variance (ANOVA) test was conducted to check the significance of collected variables on PSM. ANOVA test results are summarized in Table 3.

From the analysis, it is observed that the variables such as children accompanied and pedestrian using cell phone, frequency of attempt to accept gap, frequency of disturbances while crossing do not show significant effects on PSM.

Table 2. Descriptive statistics of variables considered for modelling

Variable name	Type of variable	Minimum	Maximum	Mean	Std. Deviation	N
Pedestrian Safety Margin (S)	continuous	-1.222	8.98	2.24	2.212	9970
Pedestrian waiting time (S)	continuous	0.0	177	11.39	18.235	9970
Pedestrian crossing time (S)	continuous	2.0	11.40	6.80	1.931	9970
Pedestrian delay (S)	continuous	-14.18	177.33	18.63	24.617	9970
Pedestrian Speed (m/s)	continuous	0.098	3.2	1.31	0.500	9970
Vehicular Gap size (s)	continuous	0.5	19.09	6.77	2.602	9970
Vehicle Speed (Kmph)	continuous	10.03	107.32	29.88	16.082	9970
Crossing Moment	categories	0.0	2.0	0.04	0.207	9970
Frequency disturbances	continuous	0.0	1.0	0.03	0.166	9970
Frequency of Attempt	continuous	0.0	2.0	0.04	0.209	9970
Pedestrian gender	categories	0.0	2.0	0.78	0.413	9970
Pedestrian age	categories	0.0	22.0	1.88	0.673	9970
Children's accompanied	categories	0.0	2.0	0.01	0.086	9970
Pedestrian Platoon size	categories	0.0	48.00	3.95	4.556	9970
Pedestrian path change behaviour	categories	0.0	1.00	0.05	0.215	9970
Pedestrian speed change behaviour	categories	0.0	1.00	0.04	0.198	9970
Pedestrian usage of cell phone	categories	0.0	1.00	0.04	0.192	9970
Pedestrian rolling behaviour	categories	0.0	1.00	0.07	0.252	9970
Concentration on vehicular gaps	continuous	0.0	1.00	0.72	0.449	9970
Types of Vehicles	categories	2.0	5.00	3.32	0.902	9970
Driver yield behaviour	categories	0.0	1.00	0.07	0.251	9970
Accepted Gap or Lag	continuous	0.0	1.00	0.03	0.156	9970
Type of gap	categories	0.0	1.00	0.30	0.457	9970
Presence of illegal parking	categories	0.0	1.00	0.67	0.471	9970
Number of lanes	categories	0.0	1.00	2.62	0.738	9970
Frequency of step backward	categories	0.0	5.00	0.04	0.346	9970
Land use type	categories	1.0	4.00	2.66	1.222	9970
Presence of median	categories	0.00	1.00	0.63	0.483	9970
Width of median opening	continuous	0.5	0.8	3.38	0.784	9970

Table 3. Significance of the selected variables on PSM by ANOVA

Variable name	F value	Signifi.	Variable name	F-value	Signifi.
Pedestrian waiting time (S)	4.275	0.000	Driver yield behaviour	0.921	0.519*
Pedestrian crossing time (S)	37.371	0.000	Pedestrian age	2.993	0.001
Pedestrian delay (S)	3.130	0.000	Pedestrian gender	2.888	0.001
Pedestrian Speed (m/s)	152.431	0.000	Frequency of Attempt	0.452	0.932*
Vehicular Gap size (s)	801.958	0.000	Crossing Moment	0.718	0.722*
Vehicle Speed (Kmph)	115.675	0.000	Frequency disturbances	1.086	0.368*
Children's accompanied	0.492	0.910*	Accepted Gap or Lag	3.741	0.000

Pedestrian Platoon size	11.594	0.000	Type of gap	4.227	0.000
Pedestrian path change behaviour	3.098	0.000	Presence of illegal parking	16.166	0.000
Pedestrian speed change beh.	2.417	0.005	Zebra marking conditions	24.264	0.000
Pedestrian usage of cell phone	1.080	0.373*	Number of lanes	39.425	0.000
Pedestrian rolling behaviour	9.314	0.000	Width of Medians	41.107	0.000
Concentration on vehicular gaps	19.972	0.000	Frequency of step backward	0.714	0.727*
Types of Vehicles	5.111	0.000	Land use type	13.962	0.000

* Not significant at 95% confidence interval with p-value >0.05.

Thereafter, Pearson correlation test was performed to identify variables to be used for modelling pedestrian safety margin values. The results of Pearson correlation analysis revealed significant correlations between PSM and vehicle gap size ($r = 0.663$; $p < 0.01$), PSM and vehicle speed ($r = 0.273$; $p < 0.01$), PSM and pedestrian speed ($r = 0.365$; $p<0.01$), PSM and pedestrian waiting time ($r = -.020$; $p<0.05$). Further, significant correlation between PSM and pedestrian crossing time ($r = -0.161$; $p<0.01$), PSM and Pedestrian delay ($r = -0.029$; $p<0.01$), PSM and pedestrian age ($r = -0.030$; $p < 0.01$) were observed. In addition to these, pedestrian path change($r = 0.029$; $p < 0.01$), pedestrian rolling behaviour ($r = -0.065$; $p < 0.01$), types of vehicle ($r= 0.023$;$p<0.05$), accepted gap/lag ($r =-.031$;$p<0.01$), Type of gap ($r =-0.023$; $p < 0.05$) also had significant correlation with PSM values.

5. PEDESTRIAN SAFETY MODEL

Based on the identify variables, multiple linear regression (MLR) approach was adopted to model pedestrian safety margin. In the MLR model, the PSM was considered as a response variable over the selected explanatory variables. The developed model can provide idea regarding pedestrian safety based on pedestrian, vehicular, and demographic characteristics. Since the safety margin values were observed to vary with pedestrian and vehicle driver behavior ranging from negative values to positive values, hence, the variation in safety margin values can be better explained using normal distribution. The MLR model is a most common modelling technique for linear continuous dependent variable in order to build a correlation between independent variables and dependent variable and the model framework is given below:

$$PSM = \beta 0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \text{- - - - - - - - - -} + \beta_n X_n$$

PSM = Pedestrian Safety margin Values; $X_{1\text{-}n}$ = explanatory variables; $\beta_{1\text{-}n}$ = estimated parameter s from the model; β_0 = y-intercept of regression line.

Total of 13672 data points were used for modelling and validation. As explained in the previous section, PSM data (9970 data points) for location I-VII was used for modelling, while PSM data (3702 data points) from location VIII-IX was used for validation of the developed model.

The PSM was considered as the response variable and the remaining variables are explanatory variables. The MLR model results show that 14 out of 28 predictors have significant effect on PSM. The model fitting was statistically significant (refer Table 4) with selected independent variables. Further, the variable selection was considered with stepwise regression analysis and there are several variables such as pedestrian waiting time ($t = -0.995$, $p =0.320$), Pedestrian delay ($t=-0.310$, $p=0.757$) crossing moment ($t =0.165$, $p= 0.869$), Frequency of disturbances ($t=1.171$, $p=0.242$), Frequency of attempt ($t=0.165$, $p=0.869$), children accompanied ($t=-1.689$, $p=0.6091$), pedestrian speed change beh. ($t=-0.755$, $p=0.450$), pedestrian use of cell (t=0.514, p=0.607), Types of vehicle (t=-0.693, p=0.488) frequency of step backward (t=-1.590, p=0.112) which were excluded from the model, as they were not showing significance on PSM at 95% confidence level.

Table 4. PSM model fitting results

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	25407.887	13	1954.453	832.565	0.000
Residual	23371.786	9956	2.348		
Total	48779.673	9969			

Table 5. PSM model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
	0.722	0.521	0.520	1.532	.000	7.667	1	9956	.006	0.683

Pedestrian Safety margin model is summarized in Table 5. All estimated values (tolerance values are above 0.2, VIF values are lower than 10) indicate that the significant independent variables are not correlated. The goodness of fit measure R^2 is equal to 0.521 and Adjusted R^2=0.52 which indicates that 13 predictors at 95% confidence interval explains 52.00% of variance in PSM. It can be noted from the Table that, vehicular gap, rolling behavior, pedestrian speed, concentration on vehicular gap, number of lanes, presence of marking, presence of illegal parking and vehicle speed have effect on the values of PSM compared to other variables.

Table 6. Pedestrian safety margin model

Variable	Estimated coeff.(β)	Std. Error	t	Sig.	95.0% Confidence Interval for B		VIF
					Lower Bound	Upper Bound	
Constant	-2.413	0.097	-24.980	0.000	-2.602	-2.223	
Vehicular Gap size (s)	0.516	0.006	81.490	0.000	0.504	0.529	1.154
Pedestrian Speed (m/s)	0.922	0.033	27.601	0.000	0.856	0.987	1.185
concentration on vehicular gaps	1.006	0.064	15.621	0.000	0.880	1.132	3.557
Vehicle Speed (Kmph)	0.016	0.001	14.736	0.000	0.014	0.018	1.284
Number of lanes	-0.416	0.039	-10.766	0.000	-0.492	-0.340	3.457
Presence of illegal parking	0.518	0.059	8.734	0.000	0.402	0.635	3.316
Pedestrian rolling behaviour	-0.400	0.062	-6.453	0.000	-0.521	-0.278	1.033
Driver yield behaviour	0.197	0.035	5.664	0.000	0.129	0.265	1.034
Accepted Gap or Lag	-0.472	0.099	-4.771	0.000	-0.665	-0.278	1.014
Land use type	-0.112	0.018	-6.167	0.000	-0.148	-0.076	2.090
Presence of marking	-0.348	0.057	-6.158	0.000	-0.459	-0.237	3.356
Pedestrian Platoon size	0.013	0.004	3.478	0.001	0.006	0.020	1.163
Pedestrian age	-0.064	0.023	-2.769	0.006	-0.109	-0.019	1.014

** Significance at 95% confidence interval with P-value < 0.05; VIF: variation inflation factor;*

The final model takes the following form:

PSM =-2.413+0.516* *VGAP* +0.922* *PS+1.006* VGAPCONC* -0.112LU T* + 0.016 * *VSPEED +0.518*VPARK -0.400* R_BEH* -0.472* *ALAG/GAP +0.013*PPZ*-0.197 * *DRYBEH* -0.416**NLANE* -0.348**POM*-0.0641**PAGE.***

Where, *VGAP*= Vehicular Gap; *PS*- Pedestrian Speed m/s; *VGAPCONC*= Concentration on Vehicular Gaps; *VS*= Vehicle Speed Km/h; *VPARK*= illegally vehicle parked; PPZ= Pedestrian Platoon size; *POM*= Presence of Marking; *ALAG/GAP* = Accepted Gap or Lag; *R_BEH* = Pedestrian rolling behaviour; *NLANE*= Number of lanes; *AGE*= Age of Pedestrian; *LUT*-Land use type; *DRYBEH*=Driver Yielding Beha.

5.1 Validation of PSM Model

The calibrated PSM model was validated with data of 2-lane undivided road (ISBT Chandigarh) and one location of 4-lane divided road (Ahmedabad). The predicted values were calculated by substituting the values of variables in the obtained model. Thereafter, the predicted values were compared with the observed values. A graph was plotted between observed and predicted values, with a line passing through origin (zero) and is shown in Figure 3. The results showed that the developed MLR model has good prediction proficiencies for estimating the minimum PSM for road crossing behaviour of pedestrian at uncontrolled midblock crosswalk section under Indian conditions. Mean Absolute Percentage Error (MAPE) is calculated to corroborate the proficiency of the model. According to Lewis scale of interpretation, estimation of accuracy (Kenneth and Ronald, 1982) for any forecast with a MAPE value of less than 10% can be considered reasonably accurate, 11% to 20% as good, 21% to 50% as reasonable and 51% or more as inaccurate. The obtained value of MAPE is 9.04 % and hence the predicted model can be deemed good.

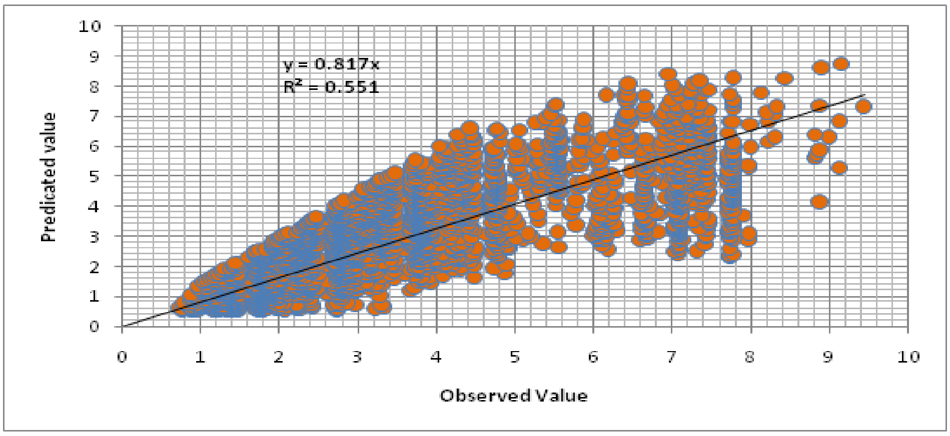

Figure 3. PSM model validation

4.2 Elasticity Analysis

Elasticity analysis was carried out as shown in Table 7. The relative effect (e*), as a normalization of the estimated elasticity in relation to the lowest elasticity, was also calculated in order to identify clearly to which extent each of the independent variables affects the dependent variable according to the following formula;

$$e = (\Delta Yi/ \Delta Xi)\ (Xi / Yi) = \beta i\ (Xi/Yi)$$

Table 7. Parameter estimates, statistical significance and elasticity in MLR model.

Variable	Estimated coefficient (β)	*p*-value.	Elasticities	
			e	ei
Vehicular Gap size (s)	0.516	0	1.57	3.25

Pedestrian Speed (m/s)	0.922	0	0.54	1.11
Concentration on vehicular gaps	1.006	0	0.32	0.66
Vehicle Speed (Kmph)	0.016	0	0.21	0.44
Number of lanes	-0.416	0	-0.48	1.00
Presence of illegal parking	0.518	0	0.15	0.32
Pedestrian rolling behaviour	-0.4	0	-0.01	0.02
Driver yield behaviour	0.197	0	0.01	0.01
Accepted Gap or Lag	-0.472	0	-0.01	0.01
Land use type	-0.112	0	-0.13	0.27
Presence of marking	-0.348	0	-0.07	0.14
Pedestrian Platoon size	0.013	0.001	0.02	0.05
Pedestrian age	-0.064	0.006	-0.05	0.11

From the above table 7, it can be observed that the Vehicle Gap has the greatest effect on pedestrian safety margin. This appear to be intuitive because, it was observed during the data extraction those pedestrians who crossed the street when vehicle was close to them had accept the smaller gaps than those who cross the street when the vehicle was far away. Thus, the former pedestrian crosses the street with more risk, which affect the safety than the latter one. Further, the pedestrian speed follows with the second higher elasticity value. This highlights that pedestrian has pronounced effect on PSM values. Positive value of elasticity indicates that any change in variable causes increase in PSM value. Further, the presence of marking also has significant effect on PSM values. Due to the presence of marking, the driver of the vehicle respects the pedestrian and gives right of way to cross the street more safely by changing its path or by reducing its speed. However, the past research shows that there is a high risk at marked crosswalks as compared to the un-marked crosswalk locations in multilane road crossing due to uncertainty of yielding behaviour of vehicle drivers (Zegeer et al., 2004). The yielding behaviour of the driver has also significant effect on pedestrian safety. Driver of light vehicles yields by changing the path, reducing the speed of vehicle to avoid the conflict compared to drivers of heavy vehicle. The variable number of lanes has an elasticity of one, and then the variable Vehicle gap size has an elasticity of 3.25. i.e., the variable, vehicle gap, affects the safety of margin 3.25 times more. Similarly, the variables, pedestrian speed have values of elasticity as 1.11; with increase in pedestrian speed the safety margin will increases with 1.11 times. Similarly, the concentration on vehicular gaps while crossing increases the pedestrian safety margin also increases. Lastly, the presence of illegal parking near the crosswalk affects PSM values. The presence of illegally parked vehicle obstructs the visibility of the pedestrian towards the approaching vehicle and therefore, affects the decision making process whether to accept the gap or not, which in-turn affects pedestrian safety (Yannis et al. 2013).

4.3 Sensitivity Analysis

Sensitivity analysis is a technique used to determine how change in independent variable influences dependent variable under a given set of assumptions. Sensitivity of pedestrian safety margin with respect to varying values of vehicular gaps, pedestrian speed, approaching vehicle speed, number of lanes and rolling behaviour is performed and shown in figure 4(a-d). As safety margin is more sensitive to vehicular gap (Refer Table 7), sensitivity analysis for different values of vehicular gap ranging from (3s-11s) is performed as shown in Figure 4(a-d).

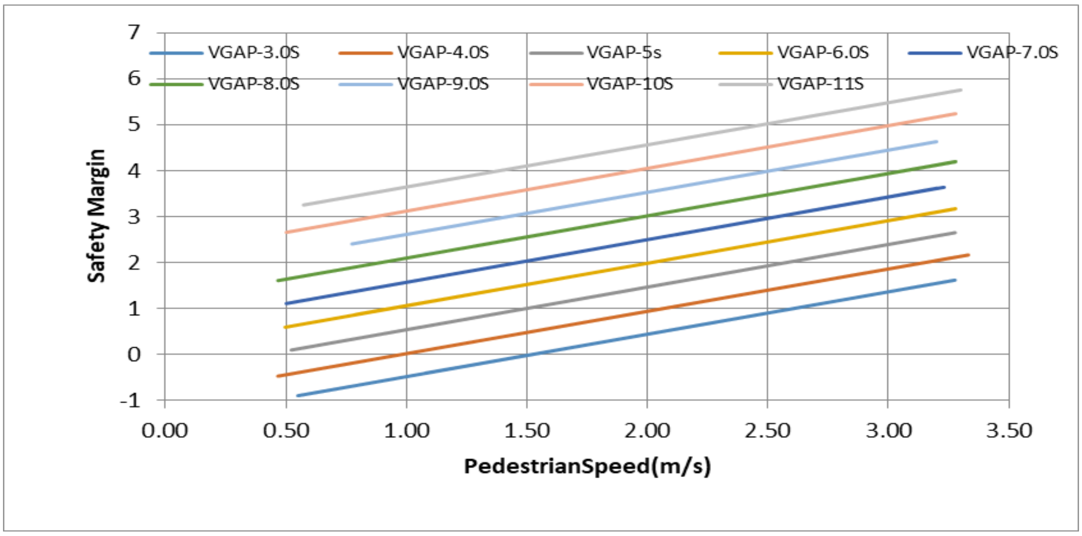

Figure 4a. Sensitivity of safety margin with respect to pedestrian speed- Different vehicle gap

From the above Figure 4(a), it can be noted for similar values of accepted gaps, pedestrian safety margin values are higher for pedestrians having higher crossing speed. Therefore, pedestrians endure lesser risks when they tend to walk faster for a given set of available vehicular gap. Further, it can also be noted from the Figure that, for similar ranges of pedestrian crossing speed, safety margin value increases with increase in vehicular gap size.

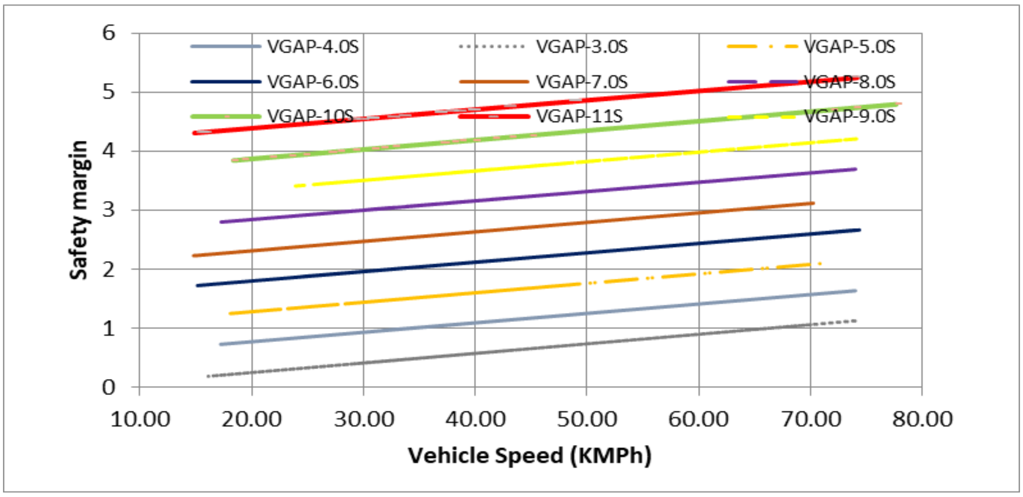

Figure 4b. Sensitivity of safety margin with respect to Vehicle speed- Different vehicle gap

From Figure 4b, the slope of all vehicle gap curves are mild with equally spaced, indicating that pedestrians maintains similar safety margin while crossing the street. It can be inferred from the above Figure that, for given value of accepted gap, pedestrian tend to keep higher margin of safety when the approaching vehicle has higher speed.

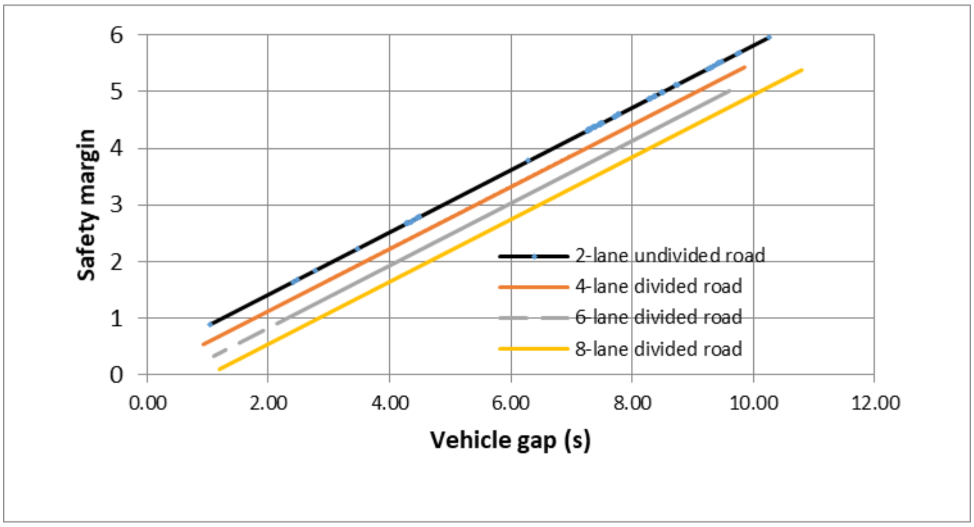

Figure 4c. Sensitivity of safety margin with respect to vehicle gap–Different lane condition

Figure 4c depicts that the slope of curve is stepper and are equally spaced, indicating uniform change in values of safety margin with respect to vehicular gap for set of available vehicular gaps. It can be noted from the above figure that, roadway geometry has significant effect on pedestrian safety margin values. For varying ranges of vehicular gaps, pedestrian safety margin values were observed to be higher for 2-lane undivided roadway geometry compared to other configurations. This can be attributed to presence of contra-flow and as result pedestrian exhibit cautious crossing behavior. Further, for divided roadway geometry, lower values of pedestrian safety margin can be noted for 8-lane divided roadway configuration compared to other configurations.

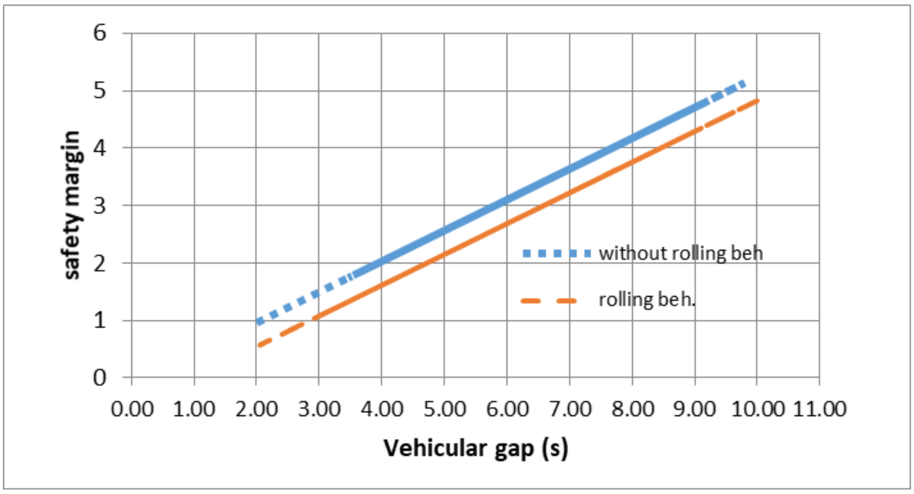

Figure 4d. Sensitivity of safety of margin with respect to vehicle gap–Different rolling condition

From Figure 4d, it can be observed that the slope of all curve for vehicle gap are stiff and very close to each other, indicating that pedestrians maintains similar safety margin while crossing the street. When the pedestrian crosses the road with rolling behaviour for vehicle gap 4s-8s the safety margin is 1.60s-3.70s and without rolling behaviour safety margin is 2s-4.25s. It reveals that when pedestrian crosses the road with rolling behavior, safety margin reduces by 9 %. Therefore, pedestrian exhibiting rolling behavior endure more risks during crossing.

Interestingly, it can be noted from the above Figures, that, slope of the graph is steeper for pedestrian crossing speed compared to vehicular speed. This indicates that, pedestrian safety margin values are more sensitive to pedestrian speed compared to vehicular speeds and the same can be contemplated from the results of elasticity analysis (Refer Table 7). Further, lane configuration and pedestrian crossing behavior (with and without rolling gap) also has significant effect on pedestrian safety margin values.

6. DISCUSSION ON DIFFERENT VARIABLES

6.1 Demographic Characteristics

From the developed PSM model results, pedestrian age has significant effect on PSM values at unprotected mid-block crosswalk under mixed traffic conditions. Pedestrian individual characteristics namely, gender and age influences pedestrian safety. Female pedestrian waits for adequate gap and feel safe to cross the street when approaching vehicle is a heavy vehicle. The elder pedestrian experience lower safety in their road crossing as compared to rest because elder pedestrian crosses the road with lower walking speed taking higher crossing time and high risk. The results are in line with the existing research studies (Oxley et al., 1997, 2005; Lobjois and Cavallo, 2007, 2009).

6.2 Behavioural Characteristics

At unprotected mid-block crosswalks (unsignalized), pedestrians more frequently interact with vehicles while exhibiting different behavioural characteristics such as rolling behaviour, increase in speed, change in crossing path, concentration on vehicular gap and pedestrian platoon. The study found that with for rolling behaviour and speed change condition, pedestrian crossing risk is more compared to non-rolling behavior. Pedestrian platoon size has a positive effect on pedestrian safety (Leden, 2002), which highlights that pedestrians when crossing in group are at lesser risks compared to individual pedestrian. This can be attributed to the fact that as the group of pedestrian crosses, vehicle driver often yields the right of way by either reducing the speed or change in path. Some other research studies have reported that the pedestrian platoon size may have a negative effect (viz., increase in conflict) because of a decrease in pedestrian speed with an increase in-group size (Zhuang and Wu, 2012). The safety margin may decrease with an increase in platoon size because of the reduction of pedestrians' speed (Kadali and Vedagiri, 2016) psychologically in platoon or group behaviour while crossing, the shy pedestrian feel safer in-group behaviour. The rolling behaviour has negative effect on safety margin. Due to rolling behavior, the pedestrian tend to accept smaller gaps instead of waiting for larger gap and as a result endure higher risks. Additionally, the driver yielding behaviour would also increase with increase in platoon size, which would increase the probability of pedestrian road crossing in this case many time the pedestrian force the driver to reduce the speed for right of way. Another important aspect about the pedestrian behaviour is concentration of vehicular gap, which means pedestrian looking at vehicles. While extracting the data, it was observed that, young/child pedestrian cross the road running without concentration on vehicular gap this behaviour is very dangerous from safety point.

6.3 Land Use Characteristics

In the present study, land use has significant effect on the pedestrian safety. Land use is classified as Mixed type, shopping, Residential, Rail transit. It is well articulated that the behaviour of pedestrian changes with the land use. It can be observed that mean safety margin is significantly higher for mix type and rail transit compared to shopping and residential. In case of shopping and residential, most of the pedestrians cross the road for the purpose of shopping, commercial, business, educational and other activities under free environment (free from time pressure) as they travel with personalized vehicle which is indifferent to public transportation schedule. Therefore, pedestrian's exhibits lesser aggressive behaviour and they are relaxed during performing different activities or crossing the road and wait at curb side till enough (safe) gap is not offered by approaching vehicles in each lane at different stages of crossing. In case of mixed type, rail transit most of population are commuters in selected site and they have to move from one zone to other in order to complete the trip, need to switch the mode more than one and possible direction as well. While changing the direction, pedestrian has to cross the section of road to pick up next mode of transportation. In this context, pedestrian behaviour is different because pedestrian has to reach at destination point as early as possible without bearing additional delay at mid-block crosswalk as a result safety is significantly reduced.

6.4 Traffic Characteristics

The present study result shows that vehicular gap has significant contribution on the PSM. It indicates that with an increase in accepted vehicular gap size, there is an increase in PSM value. From the results, it is also observed that pedestrians are at more risk while they accept successive gaps than lag (the first vehicle gap, i.e., available gap immediately after arriving at the curb or median) and the probability of non-conflict with approaching vehicle is higher when pedestrians accept successive gaps when compared to pedestrians accepting the lag. Further, it can also be observed that, higher pedestrian safety margin values are observed when the approaching vehicle is travelling at higher speeds.

6.5 Vehicular Characteristics

In India, 2W/3W vehicle dominate the vehicle composition (Figure5a). Pedestrians will more likely cross the road by maintaining least marginal vehicular gap for smaller vehicles (two-wheeler and three-wheeler) as compared to heavier vehicles (truck/bus). However, the pedestrians are more cautious when the approaching vehicle is car or two-wheeler, which can be attributed to higher vehicular speeds. Further, the results show that increase in speed of approaching vehicle significantly increases the PSM value. It may be attributed to the fact that, pedestrian tend to cross at higher speed when they perceive that the approaching vehicle has higher speeds. This may be treated as risky behavior.

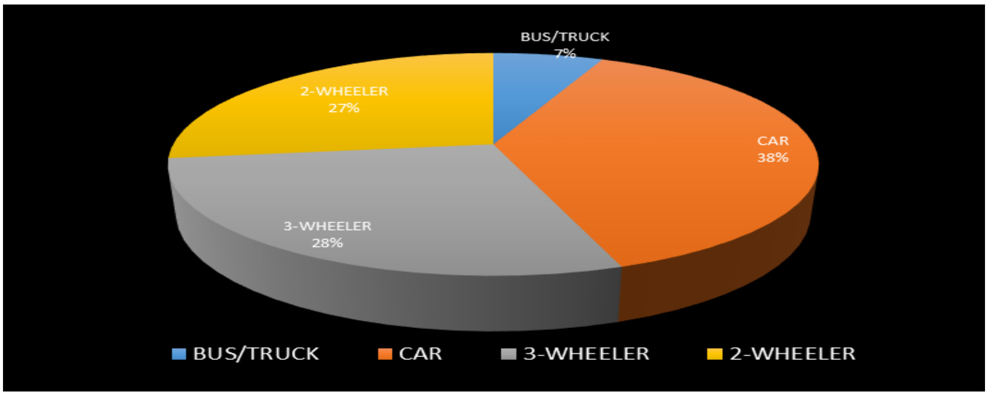

Figure 5. Vehicle composition

Earlier studies have reported that the increase in vehicle speed increases the pedestrian risk taking behaviour and crash rate (Garder et al 2004, Tung et al., 2008; Liu and Tung, 2014). In addition, the results indicate the decrease in pedestrian accepted vehicle gaps with an increase in driver yield behaviour and in such situations, pedestrian show high interaction with vehicles that further decreases the PSM values. In developing countries, driver yielding behaviour to pedestrian is observed with two-wheeler by changing the path, reducing the speed, Car by reducing the speed and provide right of way to the pedestrian. Female pedestrian feel safer when the approaching vehicles are heavy vehicles, which may be due to lower approaching speed compared to light vehicles.

5.6 Geometrical Characteristics of Roadway

With the increase in the number of lanes (road width), there is a significant increase in safety margin values, while pedestrians are crossing the road, which can be attributed to significant difference in traffic flow characteristics and pedestrian crossing behaviour. Figure 6 depict that mean safety margin value is significantly higher for eight lane divided road (3.66s) six-lane divided roadway (2.40s) as compared to four lane divided roadway (1.60s) or two-lane undivided (1.40s).

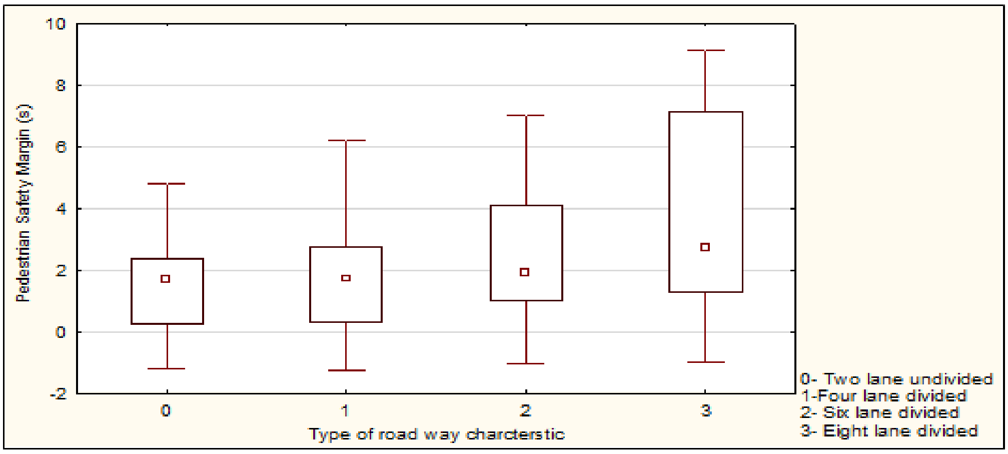

Figure 6. Pedestrian mean safety margin lane wise

However, for similar set of traffic flow characteristics and pedestrian crossing behaviour, PSM values for a given value of accepted gap decreases and the same can be contemplated from the elasticity and sensitivity analysis (Refer Table 7 and Figure 4c).

6. CONCLUSIONS

The present study attempts to evaluate pedestrian safety at urban midblock crosswalk under mixed traffic conditions. Towards this purpose, pedestrian safety was evaluated using pedestrian safety margin (PSM) as a surrogate measure of safety. Pedestrian safety margin values were extracted from the recorded video for varying roadway geometry, land-use and traffic characteristics. Further, the study develops pedestrian safety margin model using multiple linear regression approach by correlating pedestrian safety margin values with demographic, pedestrian and traffic characteristics. Some of the important findings drawn from the present study are as follows:

- Pedestrian safety margin values are significantly influenced by vehicular gap size, pedestrian speed, and vehicular speed, presence of marking, pedestrian crossing behavior (with or without rolling behavior), roadway geometry and drivers yielding behavior.

- The result of elasticity analysis showed that Vehicle Gap size, vehicle speed, pedestrian speed , concentration on gap, platoon size has the greatest effect on pedestrian safety margin, further the pedestrian rolling behaviour , presence of marking , age , no. of lanes , land use type , driver behaviour has also significant effect on pedestrian safety margin values.
- Sensitivity of pedestrian safety margin is analyzed with respect to vehicle gap accepted and pedestrian speed, number of lane, age, illegal parking, and rolling behaviour.
- Pedestrian safety margin increases with increase in size of vehicular gaps. Further, value of pedestrian safety margin increases, when pedestrians tend to cross at higher speed.
- With increase in the speed of approaching vehicle, safety margin value decreases by 28.57 %.
- With addition of one lane, pedestrian safety margin increases. Therefore, roadway configuration significantly influences value of pedestrian safety margin.
- Pedestrian crossing behavior has significant effect on pedestrian safety margin values. Pedestrians exhibiting rolling behavior endure higher risks. When the pedestrian crosses the road with rolling behavior, the safety margin value reduces by an average 9.14 %.
- From the study, it was found that pedestrians are more likely to maintain least margin values with small vehicles such as two-wheeler (2.06s), auto rickshaw (2.24s), four-wheeler cars (2.68s) compared to heavy vehicles (3.303s) under mixed traffic conditions.

The presented model results are limited to represent the pedestrian safety at unprotected mid-block locations where similar geometric and traffic characteristics exist. The results suggested that an increase in pedestrian safety and non-conflict with an approaching vehicle could be achieved by controlling vehicle speed at unprotected mid-block crosswalks. The study results also indicate the importance of presence of marking to reduce conflict with an approaching vehicle under mixed traffic conditions.

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