Evaluating Safe Distance for Pedestrians on Urban Midblock Sections Using Trajectory Plots

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Abstract

Crossing by pedestrian at-grade on Indian urban roads is a very common phenomenon. Pedestrians cross the road at any undesignated locations to access the residential and commercial lands. Crossing by pedestrians is essentially a gap acceptance process where the pedestrian would evaluate the gap available in all the lanes to be crossed before entering the road. Availability of the gap would depend on traffic volume in the lane and acceptance (or rejection) of the gap would depend upon the perception of the pedestrians about the gap. This pedestrian-vehicle interaction is a complex phenomenon and has deep safety implications. Traffic conflict technique (TCT) is used by many researchers to quantify such interactions and time based surrogate safety measures have been suggested. In the present study, the distance based surrogate safety measure "Safe Distance (SD)" has been introduced based on the profound analysis of 310 separately identified pedestrian-vehicle interaction instances. The position of the pedestrian and the interacting vehicle was tracked, and the trajectory was plotted to visualize their lateral and longitudinal movement. Further, SD value was worked out for two separate cases, namely, vehicle pass first (VPF), and pedestrian pass first (PPF) based on pedestrian-vehicle interaction. Safety-Index threshold value has been developed for different category of vehicles based on vehicle speed as a variable. Results of the study reveal that the pedestrian will be at higher risk when SD is 1.75 m for VPF case and 19 m for PPF case. This study results can be a supplement to the existing guidelines for pedestrian safety, and also provide insight to the practitioners in developing safe and efficient traffic facilities.

Keywords: Pedestrian crossing, Safe Distance, Safety Index

1. Introduction

Traffic collisions have been among the greatest health hazards in the world. According to the World Health Organisation (WHO) report 2015 (WHO, 2015), each year, more than 1.2 million people die worldwide on the road. Road traffic deaths among those who are least protected (pedestrians, cyclists, and motorcyclists) are intolerably high (almost half of the total deaths). Most of the traffic facilities are

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designed with the focus on the needs of motorized vehicles, but 49% of total deaths in the road occur among pedestrians, cyclists, and motorists. Approximately 275000 deaths a year are among the most vulnerable road users, pedestrians, which is around 22% of total road traffic deaths. The main reason for severe injuries to pedestrians is the direct impact with vehicles in addition to being thrown onto the road. Among all deaths on roads worldwide, victims are mostly youngsters aged 15 to 29 years. So, road accidents are one of the leading causes of deaths of young human resource. Moreover, the road traffic deaths and injuries in developing and underdeveloped countries are responsible for an economic loss of up to 5% in developing countries and GDP loss of 3% overall world. Statistically, around 50 million people incur nonfatal injuries every year due to road accidents. (WHO, 2015)

Figure 1: Pedestrian Crossing Scenario at Urban Midblock Section

Accident scenario in developing countries is more dangerous. In India, around 1374 accidents and 400 deaths took place every day on the road. Out of the total deaths reported due to road accidents, 54.1 percent were from age group 15 – 34 years, and pedestrian death recorded about 9.5% (MoRTH, 2016). Besides, the number of road accidents, killings, injuries, and the proportion of fatal accidents has been continuously increasing. This situation forced traffic facility designer to rethink about existing design practice. Due to insufficient walking and crossing facility for pedestrian, mostly they use regular traffic lane for walking and crossing that may lead to interaction between vehicle and pedestrians (Figure 1). The pedestrian-vehicle conflict is utterly different than vehicle-vehicle conflict, due to two reasons, firstly, pedestrian is more flexible than a vehicle, and secondly, this direct conflict will make them highly vulnerable. It was found that studies on the pedestrian-vehicle conflict at midblock sections have not given enough focus due to its inherent difficulty of observing and measuring the pedestrian behavior. To suitably model pedestrian crossing at midblock locations, it is essential to specify the geometrical characteristics such as length, pedestrians, and driver's visibility conditions and other relevant crossing characteristics. Inherent affecting characteristics can regard physical features or behavior of individuals (pedestrians or drivers). Hence, it turns out to clear the difficulty to define a model which can recapitulate such a multiplicity of pedestrian behavior, physical and environmental factors, providing reliable and useful results without a superfluous difficulty and/or data requirements. Moreover, historical collision data are insufficient and commonly incomplete as it is recorded by a traffic police officer based on his experience. So, the study has been carried out to come up with a concept of new surrogate safety measures to quantify pedestrian safety based on distance. The advantage of distance based safety parameter is that it is easily perceivable than time-based safety parameters. This study may provide some positive insight into the ongoing research in the area of pedestrian safety.

2. Literature review

Most of the researchers have attempted to study traffic safety using mainly two approaches, namely, macro-level approach and microlevel approach. Lovegrove and Sayed, 2006 and Lovegrove and Sayed, 2007 used macrolevel approach to provide a safety planning decision-support tool to address road safety before problems emerge.

Individual safety is a major concern at micro-level, where the process of traffic collision or conflict is described. The framework of organizing all traffic encounters into a severity hierarchy based on some operational severity measure has been proposed by Laureshyn et al., 2010. Zegeer et al., 2006 developed an index to prioritize intersection crosswalks with respect to pedestrian safety. Minderhoud and Bovy, 2001 introduced two new safety indicators, Time Exposed Time-to-collision indicator (TET) and the Time Integrated Time-to-collision indicator (TIT) based on the time-to-collision (TTC) notion suitable for comparative road traffic safety analyses at the intersection. Gettman and Head, 2003 introduced surrogate measures like time to collision, post-encroachment time, deceleration rate, maximum speed, and speed differential to measure the severity and potential of the conflict. Gettman et al., 2008 developed a software tool (SSAM—an acronym for the Surrogate Safety Assessment Model) for deriving surrogate safety measures for traffic facilities from data output by traffic simulation models. Archer, 2004 found that Time-to-Accident provides the most useful and relevant safety information of the three safety indicator concepts (time-to-accident, time to collision, and post-encroachment time) used. In one latest study, Babu and Vedagiri, 2017 observed conflicts at an unsignalized intersection using two surrogate measures, PET and the corresponding speed of conflicting through the vehicle. Considering both the surrogates, the required deceleration rate (RDR) for all the observed conflicts were obtained, and critical conflicts were determined using the threshold value of RDR as the maximum acceptable deceleration rate. Authors found that there are significant percentages of observed conflicts which are critical at all the intersections.

In the case of pedestrian and vehicle interaction, a pedestrian is more flexible with lesser traffic restriction than vehicles. Researchers have tried to use one or a combination of such surrogate parameters or defined new parameters as a safety measure. Kaparias et al., 2010, Institute of Highways and Transportation Conflicts Technique (IHTCT), the new vehicle-pedestrian conflict analysis technique has been introduced by Kaparias et al., 2010. Ismail et al., 2010 assessed TTC, PET, Gap time (GT), and deceleration-to-safety time (DST) regarding the severity of traffic conflicts using an automated system. Among all these indicators, the result showed that PET is the most reliable parameter for detecting important conflict events. Hagiwara et al., 2008 measured a driver's avoidance behavior according to the time lag, defined as the interval between the time that the right-turning (left-turning in the case of USA) vehicle reaches the conflict point and the time that the pedestrian coming from the right side reaches the conflict point. Hasson, 1975 introduced the parameter called time advantage (TAdv), which is similar to the expected PET for each moment to describe situations where two road users pass the same spatial area at different times. Zhang et al., 2011 compared one hundred groups of pedestrian and vehicle (P&V) interactions based on VPF) and pedestrian pass first (PPF) cases among different safety scenes. The results showed that the distance and speed values are different from the cases between VPF and PPF and time Difference to Collision (TDTC) values are related to safety. Zhang et al., 2012 defined the time difference to collision (TDTC) parameter as a variation from TTC and PET to fit the pedestrian-involved potential collisions/ conflicts, analyzed the interaction behavior between pedestrian and vehicles, and validate the TDTC parameter in indicating pedestrian safety. Zhang et al., 2014 developed a scene-based pedestrian safety performance evaluation model. Chen and Wang, 2015 proposed a cellular automata (CA) model to simulate the interaction of vehicle flows and pedestrian crossings. Using a simulation model, the influence of the interaction of vehicle flows and pedestrian crossings on the volume and travel time of the vehicle flow, and the average wait time for pedestrians to cross was investigated. Jiang et al., 2015 created a trajectory-based data matrix to investigate TTC distribution and relationships between TTC and PED/VEH-based parameters with the intercultural comparison. Kadali and Vedagiri, 2013 studied the pedestrian road crossing behavior at the uncontrolled midblock location in India under mixed traffic condition. Pedestrian road crossing behavior at uncontrolled midblock was modeled by the size of vehicular gaps accepted by a pedestrian using multiple linear regression techniques. Also, the choice model was developed to capture the decision-making process of pedestrian, i.e., accepted or rejected vehicular gaps based on the discrete choice theory. Ujjal et al., 2016 studied the impact of vehicle-pedestrian interaction at several intersections/midblock sections. The author found that fundamental diagrams are different in different locations of the study area. Chen et al., 2016 employed evolutionary game theory and cumulative prospect theory to take into account the decision process of vehicle drivers and pedestrians during the interaction for addressing the crossing decision behavior under bounded rationality and risk. Madhumita and Ghosh, 2017 attempted using two proximal safety indicators PET and conflicting speed through moving vehicles on major roads. A critical parameter speed is introduced to determine critical conflicts as well as the severity of a resulting collision. It was estimated based on the concept of braking distance. The result showed that PET values less than the threshold do not always create critical situations when the speed of the corresponding conflicting vehicle is low and vice-versa.

In previous research works, various surrogate safety parameters have been used to quantify the micro-level parameter for pedestrian safety, mostly at intersections. Some works have also been reported at midblock location. A few studies have been reported for heterogeneous traffic without lane discipline. Mostly, the parameters used in earlier researches suggested safety-related parameters in terms of time not based on space-based. In the present study, the pedestrian safety measure given in terms of distance as it is easily perceivable.

3. Research objectives of the study

In the developing countries like India, pedestrian crossing at urban midblock section is a normally observed event. The pedestrian is the unprotected road user, and such crossings have deep safety implications. The prime objective of the present study is to evaluate pedestrian safety using a safe distance as a distance-based surrogate safety measure and to suggest threshold values of safe distance at such locations.

4. Conventional safety parameters

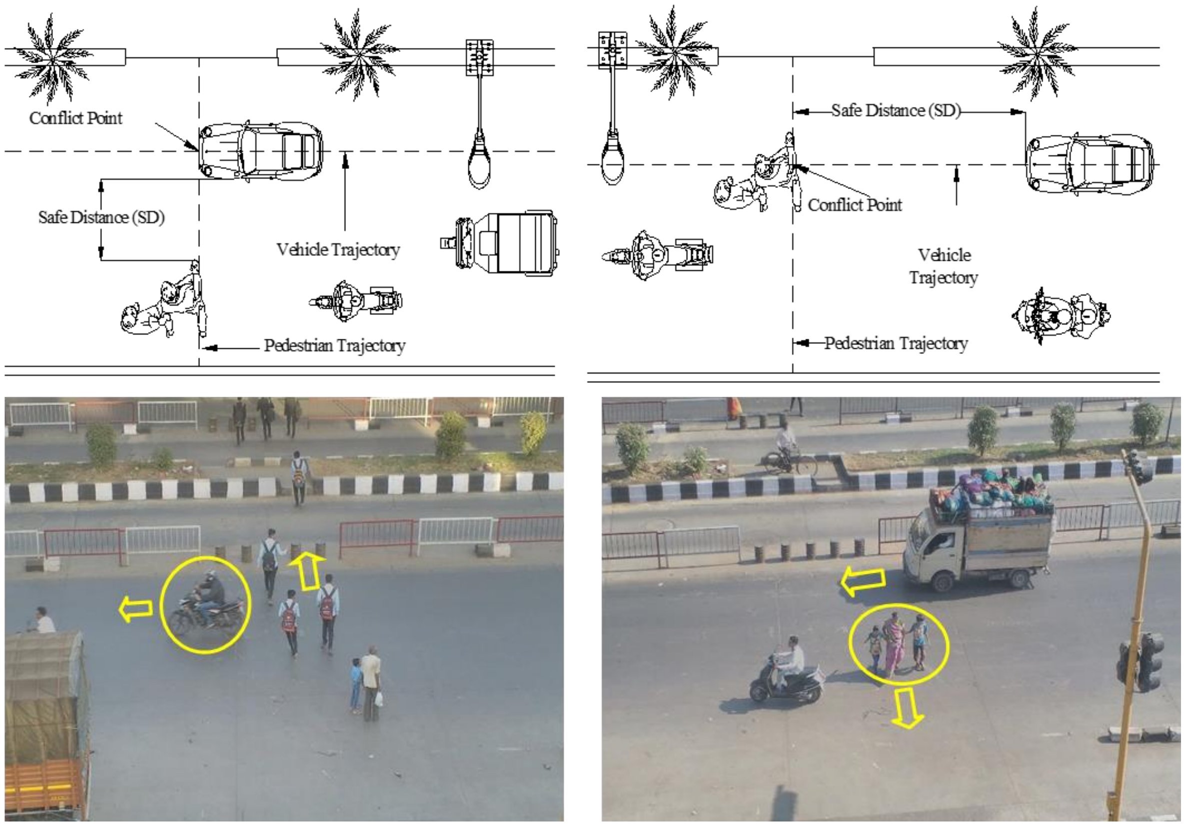
Time to collision may be defined as the time it takes for two vehicles/vehicle-pedestrian to collide if they continue on their present trajectory at the same speed. (Hyden C, 1996). Based on TTC two more indicators, the first one, time exposed to collision, measures the duration of time during which all vehicles involved in conflicts are under a designated TTC minimum threshold and the second indicator, time-integrated time to collision, is based on a summation of the integral of the TTC profile and provides a more qualitative measure of safety for the study period was given. Minderhoud and Bovy, 2001. Ismail et al., 2010 used four more indicators. Post encroachment time is the time difference between the moment an offending road user leaves an area of a potential collision and the moment of arrival of a conflicted road user possessing the right-of-way. Gap time is a variation on PET that is calculated at each instant by projecting the movement of the interacting road users in space and time. Deceleration-to-safety time is defined as the necessary deceleration to reach a non-negative PET value if the movements of the conflicting road users remain unchanged. Allen et al., 1977 ranked GT, PET, and deceleration rate as the primary measures for left-turn conflicts. The TDTC value given by Zhang et al., 2012 may be defined as an instant 't' as the time difference for a pedestrian and a vehicle to travel to the potential conflict point if their speed keeps constant. All these surrogate indicators given by various researchers are time base, here an attempt has been made to introduce space-based safety parameter.

5. Safe Distance (SD)

In this study, the space-based surrogate safety indicator has been introduced as Safe Distance (SD). SD may be defined as the distance of vehicle or pedestrian from conflict point when another conflicting object reaches the theoretical conflict point first. As SD is higher, the safety of the pedestrian is higher, and lower SD value indicates less safety and risky or aggressive behavior of driver or pedestrian. To evaluate SD, two cases have been considered. First one is vehicle pass, and the second one is a pedestrian pass first. In the case of VPF, the vehicle reaches first at the theoretical conflict point, and the pedestrian is away from it, as shown in Figure 2. In this case, the lateral distance between conflict point and pedestrian is the SD. Figure 2 indicates the PPF case in which pedestrian reaches the conflict point first, and the vehicle is away in the longitudinal direction. The distance between the theoretical conflict point and vehicle is SD in this case.

6. Data collection

To investigate the surrogate safety measure for pedestrian, a videographic survey was carried out using high-resolution camera at a selected location in Surat city, which is the fastest growing city in India with a population of 4.5 million. The survey was conducted on 3rd January 2017 from morning 9:00 to evening 7:00 under normal weather conditions at an urban atrial road on midblock location with the significant pedestrian crossflow to capture the interactions between pedestrian and vehicle. The camera was fixed on a 15m high building so that both the movement of vehicles and pedestrians can be recorded with the same camera. The study location was a 6-lane urban arterial road in addition to BRT lanes. In the median, the gap was provided for pedestrians to cross the road (Figure 3). Figure 4 shows the google earth image of study location along with camera view.



(a) Vehicle Pass First (b) Pedestrian Pass First

Figure 2: Safe distance for VPF and PPF cases

Figure 3: Image showing study location

7. Data extraction and trajectory plotting

To study the interaction between pedestrians and vehicles, a trajectory of pedestrians and approaching vehicles were plotted. To plot the trajectory a grid of overall size 40m X 8.85m in perspective view was plotted in AutoCAD 2016 software as per actual measurements are taken in the field, and the same can be overlaid on the captured camera view. The grid has been plotted with block size 1.0m X 0.44m for the first 30m to track the exact location of the vehicle in both longitudinal and lateral directions in the form of X-Y coordinates. The last 10m, which had a pedestrian crossing location, was divided in the block of 0.40m X 0.44m so that pedestrian position can be accurately tracked as shown in Figure 5.

The grid was overlaid in the captured video using Ulead VideoStudio 11. The overlaid video was replayed on large screen monitor using Avidemux 2.6.8 software which converts one second into 25 frames. After every 0.48s, the position of pedestrian and corresponding position of vehicle was tracked and recorded using a two-dimensional coordinates system. All the vehicles in the stream were divided into four categories as two-wheeler (2W), three-wheelers (3W), Car (C) and heavy vehicles (HV). The size of a vehicle was measured in the field by taking its maximum length and maximum width. In the case where more than one type of vehicle is included in a category (for example motorized two-wheeler), the average dimensions were considered. Table 1 shows the observed vehicle categories and their sizes.

Table 1 Category of Vehicle With its Size.

Vehicle type	*Vehicles included*	*Size L * B (m)*	*Projected area (m^2)*
2W	Scooters, Motorcycles	1.87 * 0.64	1.20
3W	Auto-rickshaw	3.20 * 1.43	4.48
Car	Car	3.72 * 1.44	5.36
HV	Standard bus	10.10 * 2.43	24.54

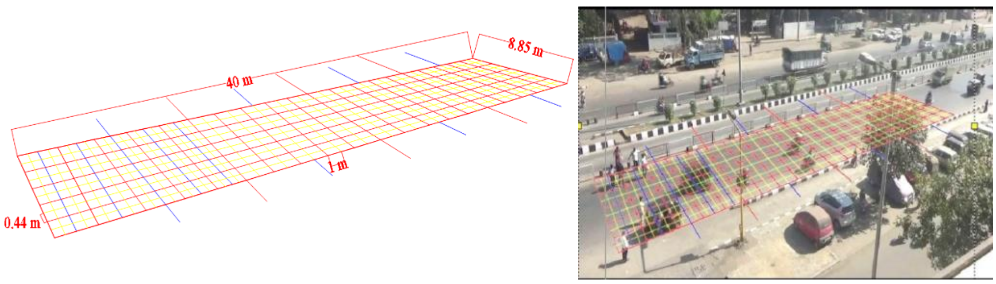


Figure 4: Grid details and grid overlaid over the video

The exact coordinates of pedestrians and vehicles interacting with the pedestrians at regular time intervals of 0.48 second were extracted and recorded in an excel sheet. Total of 310 samples of different category of vehicle interacting with pedestrians has been extracted and used for further analysis. From the raw vehicle and pedestrian trajectory data, the trajectory has been plotted using MATLAB. Longitudinal length is taken on X-axis, lateral distance is taken on Y-axis and time is taken on Z-axis. The trajectory of all samples was plotted. A sample trajectory of a pedestrian interacting with eight two-wheelers and four three-wheelers has been shown in Figure 6. At the study location, the pedestrian flow was 304 ped/hr. During data extraction, only such interaction has been considered where there is a reasonable extent on the interaction between pedestrian and vehicle.

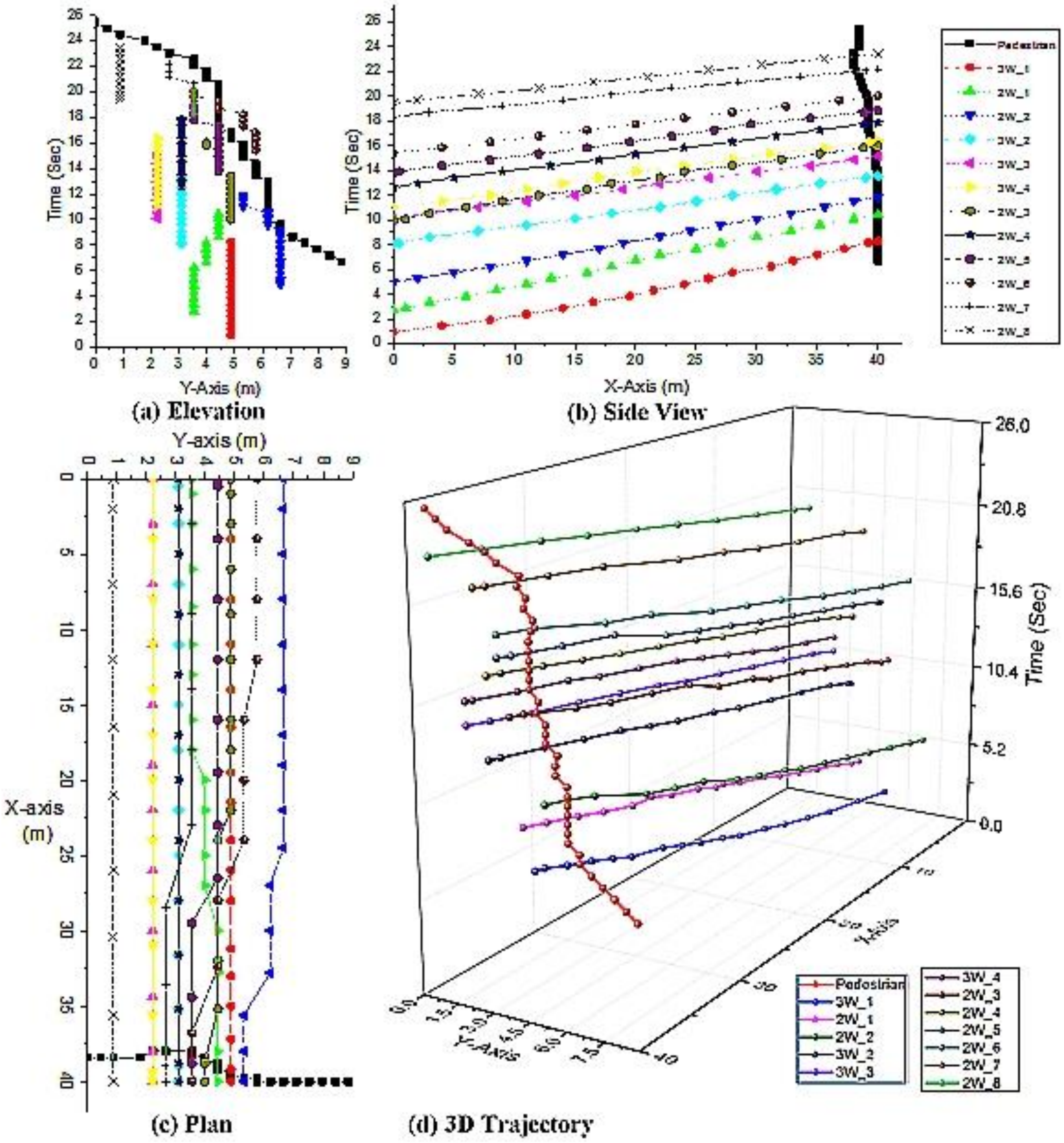


Figure 5: Trajectory and its orthographic projections

For better understanding, orthographic projections in all X-Y, Y-Z, and X-Z directions have also been plotted. From trajectory, it can be seen that the pedestrian started walking from kerb side (started from 8.85m) to cross the road. To cross the road, pedestrian has taken approximately 26 seconds and interacted with 8 two wheelers and 4 three wheelers. Moreover, while crossing the pedestrian path is zigzag, which means he used a rolling gap to pass it. In the trajectory of pedestrian, consecutive vertical dots (which shows its position) can be observed six times, which indicate that during the crossing, he waited and searched for crossing opportunity six times. In the trajectory of 2W1, 2W2, 2W3, 2W5 lateral movement can be observed, i.e., when a pedestrian was waiting, these vehicles changed their path and moved laterally to maintain the speed.

The point where both pedestrian and vehicle trajectories are vertically above each other is the conflict point. If vehicle trajectory is above pedestrian trajectory, it is VPF case and vice versa. The vertical distance between pedestrian trajectory and vehicle trajectory gives the time gap between their crossings to conflict point. The lateral distance between vehicle and pedestrian trajectory at conflict point when vehicle trajectory is below pedestrian trajectory is SD for VPF case. Same way, the longitudinal distance between vehicle and pedestrian trajectory at conflict point when the pedestrian trajectory is below vehicle trajectory is SD in PPF case. So, the detailed interaction can be done by the trajectory approach. In the present study, trajectory-based vehicle-pedestrian interaction that has been carried out is very useful for such micro-level analysis.

8. Evaluation of SD

In the present study, all vehicles are grouped into four different categories, as shown in Table-1. Composition of vehicles at the study location was as per Table 2. The proportion of two-wheeler was predominant at the study location. The proportion of heavy vehicles observed was only 0.28%. Consequently, very few samples of the interaction between heavy vehicle and pedestrian were found. The trajectory data were used to calculate SD for all 310 cases. A small program was written in MATLAB to work out conflict points, types of interaction (VPF or PPF), SD, and speed of vehicles. The descriptive statistics of SD and speed of vehicles are summarized in Table 2. As the proportion of two-wheelers, and three-wheelers were higher, more samples were obtained. On the other hand, the sample size of the car and the heavy vehicle was less on account of lesser proportion in the traffic stream. In the case of VPF, the lateral distance of pedestrian from conflict point is SD, and in the case of PPF, the longitudinal distance of the vehicle from conflict point is worked as SD. So obviously, SD in case of PPF is of the higher range which can be seen in Table 2.

Table 2 Descriptive statistics for SD and vehicle composition

Vehicle Category	*Vehicle Composition (%)*	*Type of Inter-action*	*Total Samples*	*SE (m)*				*Mean Vehicle Speed (kmph)*
				Min.	*Max.*	*Mean*	*Standard Deviation*	
2W	53.57	VPF	124	0.44	3.54	1.60	0.81	32.97
		PPF	26	2.80	33.00	15.13	8.00	31.03
3W	35.71	VPF	82	0.19	3.95	1.73	0.92	26.46
		PPF	23	4.90	37.30	16.12	9.05	24.59
Car	10.43	VPF	29	1.14	3.57	2.18	0.71	34.11
		PPF	12	3.33	38.07	19.13	11.61	32.60
HV	0.28	VPF	5	0.56	2.33	1.64	0.81	35.19
		PPF	9	13.90	39.00	26.16	9.95	32.12

As the distance between pedestrian and vehicle is more, there are lesser chances of collision/conflict as the distance between the two decreases, the chances of collision increases. Higher SD value denotes the tendency of pedestrians to keep a higher distance from approaching vehicle during crossing operation, i.e., higher safety. On the other side, lower SD value shows that pedestrian keeps lesser distance with approaching the vehicle, i.e., lesser safety. SD value is affected by many factors like pedestrian's age, gender, behavior, group of pedestrians crossing simultaneously, driver's behavior, vehicle category, vehicle speed, geometrical condition of the road, environmental conditions, etc. In the present study, the effects on the vehicle category and vehicle speed have been considered. The result shows that SD value varies with vehicle category and vehicle speed. As vehicle size increases, SD values also increases. SD value is more in the case of two wheeler than three-wheeler in spite of smaller size in VPF case due to a higher speed. Due to a lesser sample size of the car and heavy vehicle, the value of SD is lesser. In the case of PPF, the chances of collision are higher as pedestrian comes just ahead of vehicle and speed of the vehicle is much higher compared to pedestrians and hence, higher longitudinal distance from the vehicle (SD) is required safe operation. SD values were found to increase with the increase in the size of vehicles, and the smallest in the case of two-wheelers and highest in case of heavy vehicles.

9. The statistical distribution of SD

The empirical distribution of SD for either interaction types VPF and PPF are fitted with three types of hypothesized distribution, and Kolmogorov Smirnov (K-S) and Anderson Darling (AD) tests are performed in view to check the goodness of fit. Generalized extreme value distribution is found to best fit for both types of interaction cases. Figure 7 and Figure 8 show the frequency distribution for SD in both types of interactions. Table 3 shows the results of K-S and AD test performed to test the distribution. For both VPF and PPF cases, K-S statistics value and AD statistics value are less than the respective critical value at 95% confidence level, which shows that GEV distribution is well fitted.

Table 3 Estimated parameters for Log-Normal distribution for TTD

Type of Interaction	*Gen. Extreme Value Distribution*					
	K-S Stat.	*Critical Value*	*A/R*	*AD Stat.*	*Critical Value*	*A/R*
VPF	0.076	0.087	A	1.717	2.502	A
PPF	0.062	0.156	A	0.357	2.502	A

Note: A - Accepted and R - Rejected

10. Cluster analysis

Pattern classification, data mining, data compression, and pattern recognition are some of the applications of clustering based on k-mean which is closely related to several clusters and location problems (Kanungo et al., 2002). These applications include the Euclidean k-medians, the objective of which is to minimize the sum of distances to the nearest center, and the geometric k-center problem, whose objective is to minimize the maximum distance from every point to its closest center. Such a simple iterative scheme can obtain a locally minimal solution.

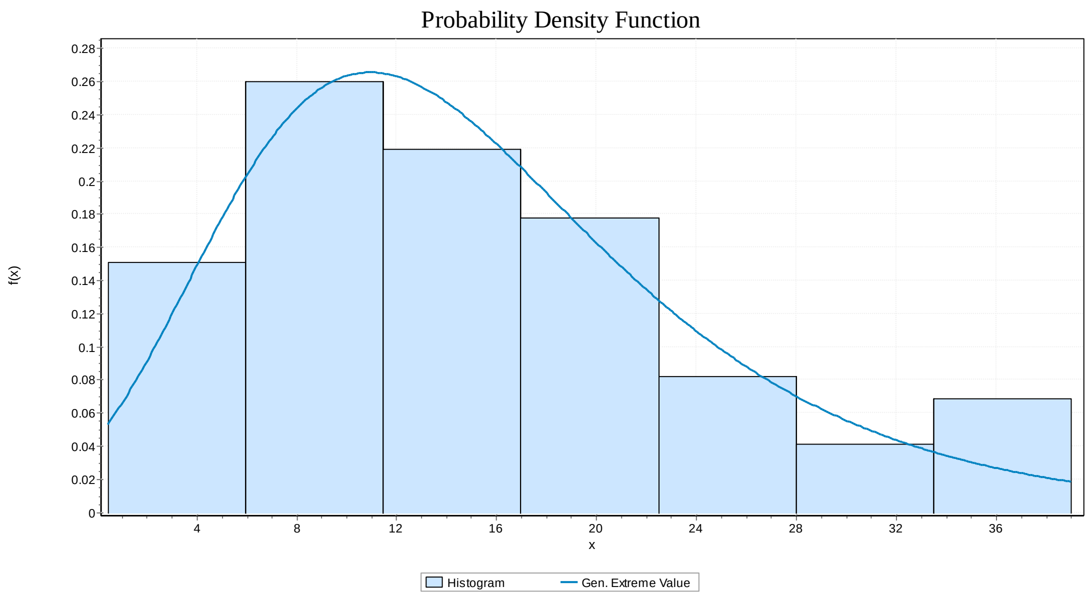


Figure 6: Probability Density Function for SD in VPF

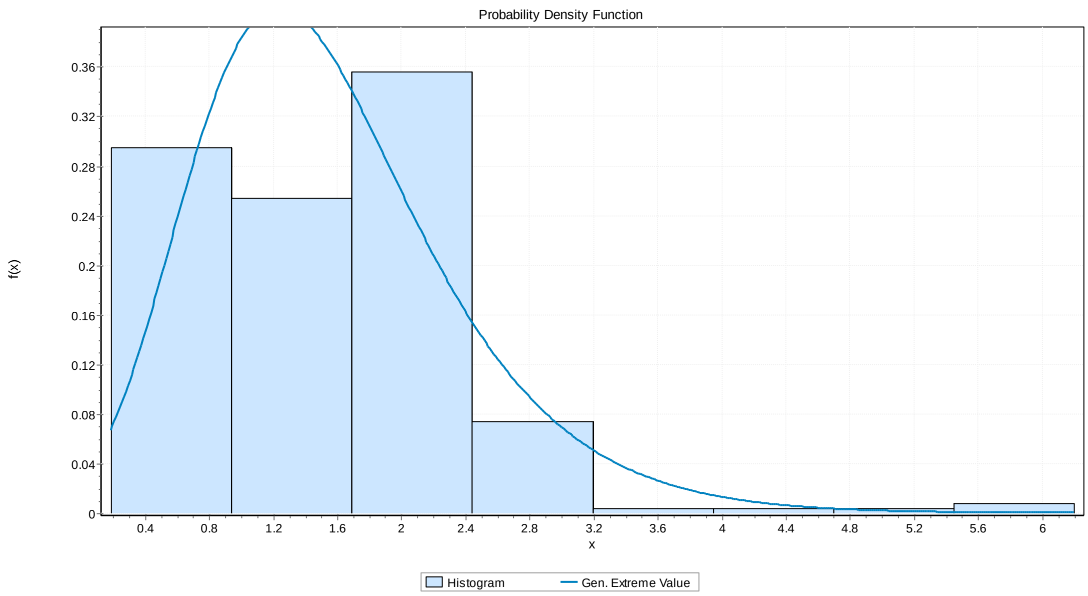


Figure 7: Probability Density Function for SD in PPF

In the present study, during data extraction, such interaction is considered that having interaction between two entities. Free movement of pedestrian without interaction with the vehicle is not found. Safety distances are worked out based on such interactions of pedestrians and vehicles. Hence the interactions are ranging from high risk to moderate risk. Therefore, to obtain the locally minimal center of each cluster with the identified cluster memberships of each variable data set and to determine the classification between two parameters, the k-mean clustering technique was used. For precise results, vehicle speed has been considered as a variable for further analysis with STATISTICA. As the data sets available in the range of high risk and low risk, cluster 1 and cluster-2 were used. To get normalized boundary delineation, 250 iterations were done. After cluster membership of each variable is defined, data points are plotted for safety margins to vehicle speed to establish the safety index thresholds by classification membership, as shown in Figure 9. The speed of the interacting vehicle is also an important parameter affecting safety along with safe distance. So, to consider the effect of speed in safe distance threshold speed of vehicle is taken as a variable.

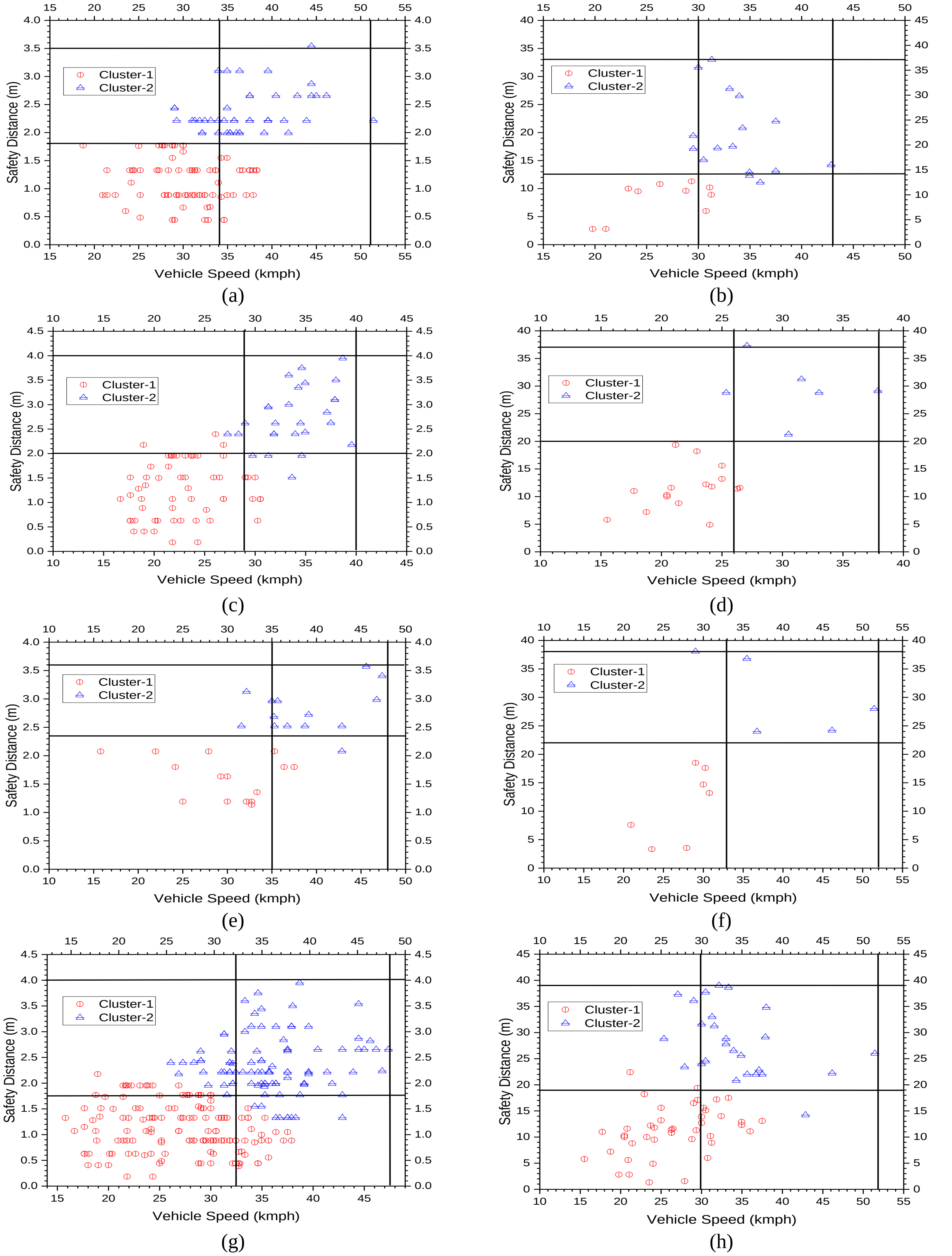


Figure 8: Scatter plots of clusters for (a) 2W-VPF, (b) 2W-PPF (c) 3W-VPG (d) 3W-PPF (e) C-VPF (f) C-PPF (g) All Vehicle-VPF (h) All Vehicle –PPF

From the cluster plot, it is difficult to delineate the exact safety index threshold as data points prescribed safety index classification fall on both sides of the boundaries. The demarcated safety indices were identified from the plots in Figure 9 by minimum overlapping of the data points on either side of the designated threshold. The reason for overlapping data points can be understood from pedestrians' behavior. Some pedestrians cross the road with safe operation and keep away from approaching vehicles while some other pedestrians take a risk and do not maintain much distance. So, due to behavioral aspects of pedestrians, such overlapping of data points have been observed. Table 4 shows the final classification of the safety index thresholds values.

Table 4 Thresholds for Safe Distance for different category of vehicles

Vehicle Category	*Type of Interaction*	*Safety Index*	*Threshold by Variable*	
			SD (m)	*Vehicle Speed (kmph)*
2W	VPF	A	< 1.75	< 34
		B	> 1.75	> 34
	PPF	A	< 12.50	< 30
		B	> 12.50	> 30
3W	VPF	A	< 2.00	< 29
		B	> 2.00	> 29
	PPF	A	< 20.00	< 26
		B	> 20.00	> 26
Car	VPF	A	< 2.35	< 35
		B	> 2.35	> 35
	PPF	A	< 22.00	< 33
		B	> 22.00	> 33
All Vehicles	VPF	A	< 1.75	< 32.5
		B	> 1.75	> 32.5
	PPF	A	< 19.00	< 30
		B	> 19.00	> 30

As the distance between pedestrian and vehicle is more, there are lesser chances of collision/conflict as the distance between two decreases, the chances of collision increases. However, the speed of the conflicting vehicle is also an important parameter. During the interaction between pedestrian and vehicle, if SD value is low and the speed of the vehicle is also less, the severity of conflict will be less as compared to a vehicle with higher speed. In the present study, the effect on vehicle category, vehicle speed has been considered. The result shows SD value varies with vehicle category and vehicle speed. As vehicle size increases, SD values also increase. In the case of two wheeler SD value is more than three-wheeler in spite of smaller size in VPF case due to a higher speed.

11. Conclusions

The present research explored the safety of pedestrians or motor vehicles concerning its interaction on each other while crossing the urban midblock stretches. A trajectory-based approach has been adopted to quantify the interaction between pedestrian and vehicle by considering two separate scenarios such as Vehicle Passing First (VPF), Pedestrian Passing First (PPF). A significant advantage of trajectory is that the pedestrian and vehicle both can be tracked in both longitudinal and later direction, which otherwise finds difficult. In the present study, the distance based surrogate safety measure "Safe Distance (SD)" has been introduced based on the profound analysis of 310 separately identified pedestrian-vehicle interaction instances. The results revealed that SD increases with the size of the vehicle and speed of the vehicle. Moreover, safety index threshold value has been given for different category of vehicles based on the types of interaction. To obtain accurate threshold value, vehicle speed used as a dependent variable. Following are finding of the present study.

1. The threshold value of safety index in VPF case and PPF are evaluated as 1.75m and 19 m respectively, below these values of safe distance pedestrian is at high risk of collision.
2. The safe distance threshold value is observed to increase with the area of the conflicting vehicle. Safe distance for 2W is observed as 1.75 m in VPF case and 12.5 m in PPF case, which is least among all category of vehicles.
3. The threshold value of safe distance for 3W has been found 2.0 m in VPF case and 20 m in PPF case which increased to 2.35 m in VPF case and 22 m for PPF case for Car.

The study quantifies the safety distance between the specific vehicle category and pedestrians. However, the study location has very less proportion of heavy vehicle, and hence, the threshold value for the heavy vehicle could not be evaluated. It is undoubtedly an important topic for further research where heavy vehicles are present in a significant proportion, and pedestrian crossing activities are present. Further, in the present study group effect of pedestrian and pedestrian characteristics like age, gender is not considered, which can affect the safety aspect. More studies are required in this direction in different countries with similar traffic conditions, and results may compare.

Contribution of the present study

The methodology and threshold value suggested in the present study may be helpful for the evaluation of pedestrian safety at a midblock crosswalk. It may also help in the design of pedestrian crossings and automated driving software. Moreover, the present research can be utilized to develop generous recommendations in terms of guidelines that can be used for the improvement of traffic operations and safety of pedestrian at the urban midblock sections under mixed traffic scenario. The space-based safety measure is easily perceivable than time-based safety factors.

Acknowledgment

Authors would like to thank Department of Science and Technology (DST), of the Ministry of Science and Technology, Government of India that subsidizes the research project entitled Traffic and pedestrian movement analysis at undesignated pedestrian crossings on urban midblock sections (File No. YSS/2014/000760).

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Acronyms used in the study

SD	safe distance
TCT	traffic conflict technique
VPF	vehicle pass first
PPF	pedestrian pass first
WHO	World Health Organisation
GDP	Group Domestic Project
MoRTH	Ministry of Road Transport and Highways
TET	time-to-collision indicator
TIT	time integrated time-to-collision indicator
SSAM	surrogate safety assessment model
PET	post encroachment time
RDR	required deceleration rate
IHTCT	Highways and Transportation Conflicts Technique
GT	gap time
DST	deceleration-to-safety time
TAdv	time advantage
P&V	pedestrian and vehicle
TDTC	time difference to collision
CA	cellular automata

2W	two-wheeler
3W	three-wheelers
HV	heavy vehicles
K-S	Kolmogorov Smirnov
AD	Anderson Darling