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Pedestrian Gap Acceptance Behavioural Modelling at Midblock and Uncontrolled Intersections

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Abstract
Pedestrian safety is one of the major concerns and pedestrian gap acceptance (PGA) behaviour depends on various characteristics of pedestrians, vehicles, geometry and environment. This study is intended to develop PGA models at various pedestrian crossing locations (mid-blocks and uncontrolled intersections). Video graphic data was collected from four different pedestrian crossing locations and extracted the required data from videos manually. The multiple linear regression (MLR) technique was used to model the pedestrian gap acceptance behaviour by the vehicular gap size accepted by the pedestrians. MLR models reveal that the frequency of attempts significantly affects the PGA behaviour only in the case of mid-blocks whereas the frequency of disturbances significantly affects only in the case of intersections. The statistical results showed that the pedestrian road crossing behaviour depends on the type of crossing location also. The results can be used to analyse the pedestrian safety levels at various crossing locations.

Author Keywords. Pedestrian gap acceptance behaviour, MLR modelling, Midblock, Uncontrolled intersection, crossing behaviour comparison.

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1. Introduction

For shorter distances, walking is common across the world and it is the most preferable option in developing countries like India. Walking helps to save fuel consumption and the environment from pollution. According to NHTS (National Household Travel Survey) national data 2001, the number of walking trips decreases as the distance to travel increases and most numbers of walking trips are possible at a distance of 0.26 miles to 0.50 miles. The number of walking/crossing trips decreases year by year not only due to an increase in the vehicular volume but also due to neglecting the importance of pedestrians and their safety.

Pedestrians are one of the most vulnerable road users and their safety is of utmost importance due to the direct exposure to an accident. According to the road accident statistics 2019 (MoRTH 2019), around 17% of pedestrian deaths in India occurred only at crossing locations and this trend is in increasing order from the years 2015 to 2019. Table 1 shows the percentage of pedestrians killed each year at crossing locations in India. The increase in pedestrian death rate is mainly due to the lack of infrastructure facilities for pedestrians. A detailed understanding of pedestrian road crossing behaviour may help to provide better infrastructure facilities for pedestrians. Improvements in the gap acceptance behaviour of pedestrians may improve pedestrian safety at crossing locations and it is possible only with the detailed investigation of factors that affects the PGA behaviour.

Year	2015	2016	2017	2018	2019
Pedestrians killed (%)	9.5	10.5	13.8	15.0	17.0

Table 1: Share of pedestrian deaths at pedestrian crossings in India: 2015-2019
(Source: http://morth-roadsafety.nic.in)

2. Literature Review

The safety analysis using the traffic conflict technique is an effective alternative way for improving the safety levels due to the correlation between the crashes and observed traffic conflicts (Yi et al. 2012). Pedestrian safety can also be evaluated based on the risk-taking behaviour of pedestrians and it is possible with the analysis of gap acceptance behaviour of pedestrians. The need for a pedestrian facility in any area decided by the waiting time of pedestrians (Jain et al. 2014). The variation of pedestrian gap acceptance behaviour can be analysed using parametric and descriptive analysis (Chandra et al. 2014). A large number of studies were conducted on pedestrian gap acceptance behaviour to investigate the pedestrian, vehicle, traffic, road geometric, environmental, and etc. parameters which affect the pedestrian gap acceptance behaviour. The pedestrian flow characteristics were significantly affected by the road width, time of the study, temperature and climatic condition (Evans and Norman 1998; Laxman et al. 2010). Pedestrian waiting time varies as they cross the road from one side road to the other side (Hamed 2001). Studies have been found that accepted pedestrian gap size depends on pedestrian characteristics like age, gender, crossing pattern, waiting time, vehicle type, vehicle speed and traffic volume (Asaithambi et al. 2016, Oxley et al. 1997, Tiwari et al. 2007, Holland and Hill 2007, and Kadali et al. 2013). Kadali et al. (2013) found that it also depends on driver behaviour, rolling gap and it does not depend on observation duration and number of observations at the curb. Pedestrians accept higher gap sizes while crossing from the curb side than the median side (Das et al. 2005). Some studies found that the risk-taking behaviour of pedestrian's was not significantly affected by the traffic volume (Papadimitriou et al. 2012). The probability of an interaction between the pedestrians and vehicles increases with the pedestrian age, male driver, trucks, freeway, frequency of attempts for finding a suitable gap and rolling gap behaviour of pedestrians (J. K. Kim et al. 2008; Kadali et al. 2013). The probability of an interaction between the pedestrians and vehicles decreases with the increase in driver age, presence of traffic signal control, inclement weather, and curved roadway (J. K. Kim et al. 2008).

Previous studies identified that the PGA behaviour depends on various characteristics of pedestrians, vehicles, geometry and environment. Lalam et al. (2020) compared the crossing speeds of pedestrians at mid-blocks and uncontrolled intersections and stated that the pedestrian crossing speed depends on the type of crossing location. Lord (1996) found that the number of traffic conflicts would be higher at T-intersections compared to X-intersections. From these statements, it is clear that not only traffic conflicts but also PGA behaviour may vary with the type of crossing location. The present study is intended to develop a PGA model at various crossing locations under mixed traffic conditions (The mixed traffic conditions or heterogeneous conditions are due to the different type of vehicles. In India, all the vehicle types share the same carriageway width without any physical segregation between the non-motorized and motorized vehicles.). Also, this study is intended to compare the crossing behaviour of pedestrians at various crossing locations to know the factors which affect the PGA behaviour in mixed traffic conditions.

3. Study Location and Data Collection

The selection of study location and collection of appropriate data from that location is an important thing before analysing any kind of traffic and transportation engineering problems. Four pedestrian crossing locations were selected for this study based on the importance of the objectives and these locations were selected in the cities of Warangal and Thiruvananthapuram, India. Generally, in India, majority of the pedestrian morning trips are observed during morning (7:00AM to 10:30AM) and evening (4:00PM to 7:00PM) periods. The video recording was performed for four hours (7:30AM-9:30AM and evening 4:30PM-6:30PM) in weekdays from each study location. The data from the videos was extracted using MPC: HC 1.7 media player and used for the analysis. Among these four locations, two are 4-legged uncontrolled intersections and the remaining two are midblock locations. All the four study locations are observed to be occupied with mixed land use characteristics and the photographs of the study locations were shown in **Figure 1** below. Four hours of traffic data were collected from each location using a high-resolution video camera. The recorded videos consist the information like pedestrian and vehicle characteristics. The geometric details measured from each study location were shown in **Table 2**.

(a) (b) (c) (d)

Figure 1: Study locations at (a) Kazipet (b) Hanamkonda (c) Hanamkonda (d) Thiruvanthapuram (Govinda et al. 2020)

Location	Type of location	Number of lanes (major road)	Lane width (meters)	Observed pedestrian volume (ped/hour)
Kazipet	Uncontrolled intersection	4	3.5	432
Hanamkonda	Uncontrolled intersection	4	3.5	463
Hanamkonda	Midblock	4	3.5	452
Thiruvananthapuram	Midblock	4	3.5	336

Table 2: Geometric details and observed pedestrian volumes at the study locations

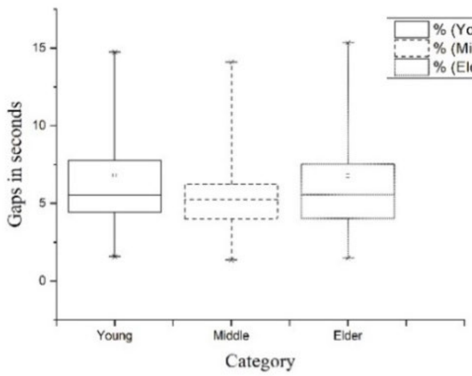
4. Results and Discussions

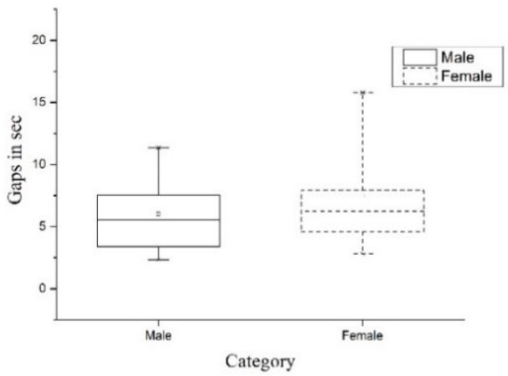
At both locations, the pedestrian crossing behaviour like pedestrian age, genders, waiting time, frequency attempts, frequency of disturbances, stages of crossing etc. were extracted from the video. The pedestrian gender and age extracted manually from the video based on the visual observations. The pedestrian gender is classified into male and female and the age is classified into children (<=15 years), young pedestrians (16-30 years), Middle age pedestrians (31-60 years), and old age pedestrians (>60 years) (Patra et al. 2017). Also, the pedestrian crossing speeds were calculated using the distance covered by the pedestrian and the time of crossing (excluding waiting time). Extracted data will be used to analyse and model pedestrian gap acceptance behaviour.

4.1. Pedestrian Gap Acceptance Behaviour Analysis and Modelling

4.1.1.Midblock Locations

Box plots were used to represent the gap sizes accepted by pedestrians according to different categories of pedestrians. The gap acceptance behaviour at midblock locations results reveal that female pedestrians accept a maximum gap of 15.787 seconds and male pedestrians accept a maximum gap of 11.336 seconds. Female pedestrians accept larger gaps than male pedestrians. Youth, middle age and old age pedestrians accept a maximum of 14.736, 14.081, and 15.625 seconds respectively. Middle age pedestrians accept lower gaps than youth and old age pedestrians. The below **Figure 2** shows the variation of pedestrian's gap acceptance concerning age and gender.





(a) (b)

Figure 2: Mean accepted gap size at midblock location w.r.t. (a) Age (b) Gender

The multiple linear regression (MLR) technique was used to model the pedestrian gap acceptance behaviour using the dependent and independent variables. Statistical Package for the Social Sciences (SPSS 20.0) software package at a 95% confidence interval was used to develop the MLR model. Gap size (seconds) was taken as the dependent variable and the independent variables includes pedestrian and vehicle characteristics. MLR was performed in SPSS software between the dependent (gap size) and independent (Pedestrian age, gender, waiting time (WT), Frequency of attempts (FOA), frequency of disturbances (FOD), presence of children (POC), and stages of crossing (SOC)) variables and the variables with a p-value less than or equal to 0.05 were included in the model. In the present study, the variable constant is related to gap size (seconds) as it is the dependent variable. A lognormal regression model was developed to find out the minimum vehicular gap size at the midblock location for the pedestrians to cross the road safely. The output obtained after considering 7 parameters

(Pedestrian age, gender, WT, FOA, FOD, POC, and SOC) yielded a model from SPSS 20.0 is depicted in **Table 3**.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.503	0.015		4.039	0.000
	Age	0.608	0.424	0.124	1.434	0.153
	Gender	-0.189	0.630	-0.024	-0.301	0.464
	WT	-0.455	0.472	-0.084	-0.964	0.336
	POC	-0.280	1.388	-0.016	-0.202	0.840
	FOD	0.005	1.048	0.000	0.005	0.996
	FOA	0.717	0.847	0.073	0.847	0.398
	SOC	-0.138	0.471	0.092	1.141	0.255

Table 3: The output from SPSS 20.0 showing MLR model results for midblock locations

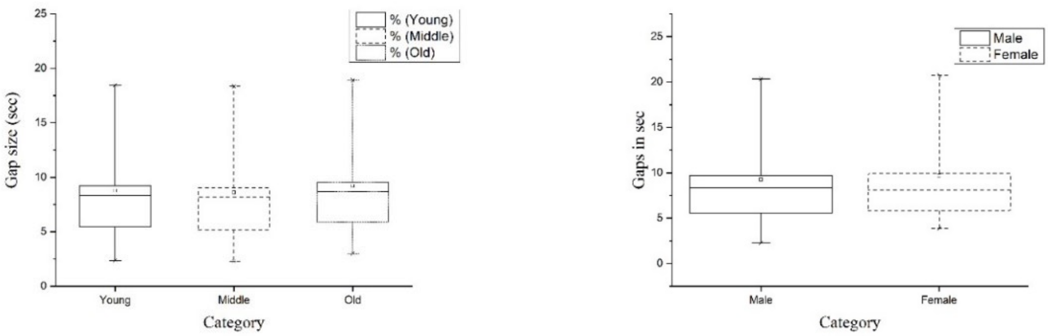
$$Log - gap = 0.503 + 0.608 \times Age - 0.189 \times Gen - 0.455 \times WT + 0.717 \times FOA - 0.138 \times SO \quad (1)$$

Where, Gen = Gender, WT=Waiting time, FOA=Frequency of attempts, SOC=Stages of crossing, POC = Presence of children, FOD=Frequency of disturbance.

The change in the standard deviation of the output variable due to the change in the input variable (viz., pedestrian age, gender, FOA, FOD, WT, and SOC) will be represented by the coefficient B in (**Table 3**). The increase or decrease in the output value due to a change in the input variable will be indicated by the positive or negative sign of coefficient B. The pedestrian accepted gap size will increase due to the increase in pedestrian age and frequency of attempts and decrease with the increase in pedestrian waiting for time and stages of the crossing.

4.1.2. Uncontrolled Intersections

The gap acceptance behaviour at uncontrolled intersections results reveal that female pedestrians accept a maximum gap of 20.766 seconds and male pedestrians accept a maximum gap of 20.359 seconds. Female pedestrians accept larger gaps than male pedestrians. Youth, middle age and old age pedestrians accept a maximum of 18.468, 18.359, and 18.921 seconds respectively. Middle age pedestrians accept lower gaps than youth and old age pedestrians. Below **Figure 3** shows the variation of pedestrian's gap acceptance concerning age and gender.



(a) (b)

Figure 3: Mean pedestrian accepted gap size at uncontrolled intersection with respect to (a) pedestrian age (b) pedestrian gender

The multiple linear regression (MLR) technique was used to model the pedestrian road crossing behaviour at an uncontrolled intersection. The detailed methodology on how to perform the MLR analysis in SPSS software was explained in section 4.1.1 above. A lognormal regression model was developed to find out the minimum vehicular gap size at uncontrolled intersections for the pedestrians to cross the road safely. The output obtained after considering 7 parameters (Pedestrian age, gender, WT, FOA, FOD, POC, and SOC) yielded a model from SPSS 20.0 is depicted in the above **Table 4**.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.672	0.027		28.180	0.000
	Age	0.158	0.023	0.082	-11.959	0.005
	Gender	-0.275	0.320	-0.035	-0.860	0.390
	WT	-0.043	0.010	-0.176	-4.256	0.000
	FOD	0.159	0.039	0.062	-3.509	0.002
	FOA	-0.168	0.361	-0.019	-0.465	0.642
	SOC	-0.025	0.273	0.183	-4.489	0.000
	POC	-0.336	0.763	-0.018	-0.440	0.660

Table 4: The output from SPSS 20.0 shows MLR model results for the uncontrolled intersection

$$Log - gap = 0.672 + 0.158 \times Age - 0.275 \times Gen - 0.043 \times WT + 0.159 \times FOD - 0.025SOC \quad (2)$$

The change in the standard deviation of the output variable due to the change in the input variable (viz., pedestrian age, gender, FOA, FOD, WT, and SOC) will be represented by the coefficient B in **Table 4**. The pedestrian accepted gap size will increase due to the increase in pedestrian age and frequency of disturbances and decrease with the increase in pedestrian gender, waiting time, and stages of the crossing.

4.1.3. Validation of MLR model

Calibration and validation are the two important things for the development of any model. Validation shows the realistic representation of the actual system. 70% of data from all locations were used for model development and the remaining 30% data was used for validation of the models. Statistical analysis helps to measure the accuracy of the model in terms of performance and validation. Root mean square error (RMSE) and mean absolute error (MAE) are the two statistical parameters used for the validation of the developed models. RMSE and MAE values for uncontrolled intersection were 1.195 and 0.020 and for midblock location 1.143 and 0.015 respectively. A lower value of RMSE and MAE indicates that the difference between observed gap size values and predicted gap size values will be less and shows a good correlation between the observed and predicted values. It is represented graphically by plotting observed gap size on the x-axis and expected gap size on the y-axis shown in **Figure 4**.

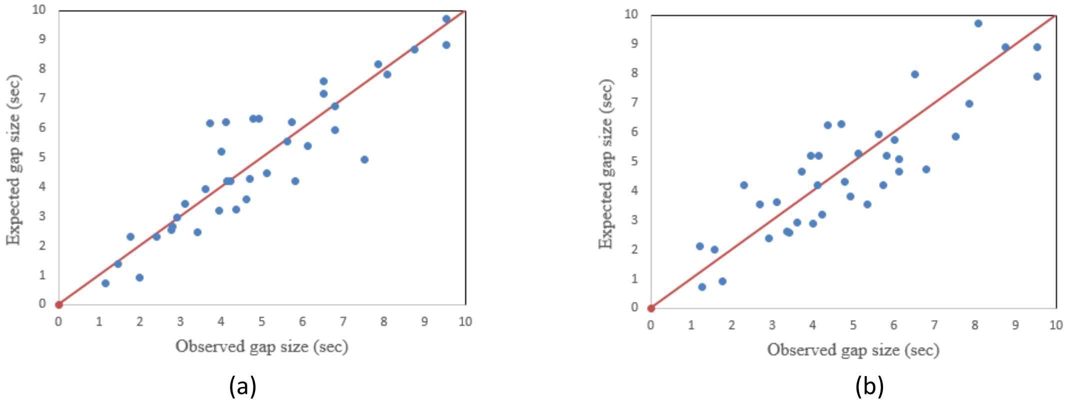


Figure 4: MLR model validation for (a) Midblock (b) Uncontrolled intersection

Residual analysis was carried out between the observed pedestrian gap size and predicted gap size values to check the appropriateness of the linear regression model. In both midblock and uncontrolled cases, the points in the residual plots follow homoscedasticity. A linear regression model was more appropriate for the present study since the random dispersion of the points around the horizontal axis. (**Figure 5**)(a) and (**Figure 5**)(b) below shows the residual analysis at midblock and uncontrolled intersections respectively.

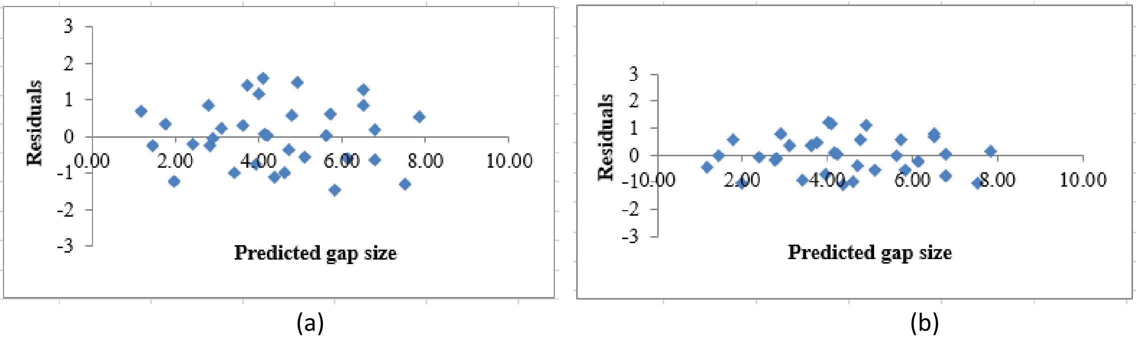


Figure 5: Residual analysis at (a) Midblock location (b) Uncontrolled intersection

4.2. Comparison of pedestrian gap acceptance behaviour

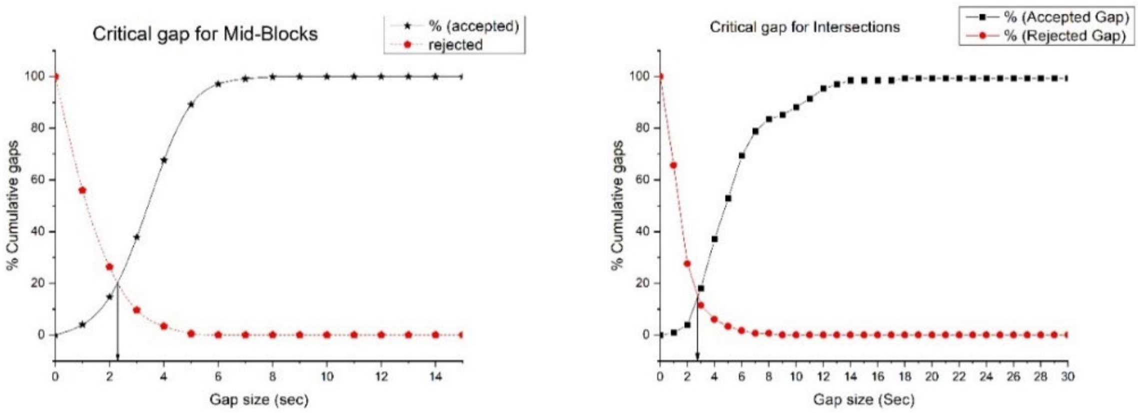
Analysing and modelling pedestrian road crossing behaviour provides possible solutions for safer pedestrian crossings and comparing this behaviour at different crossing locations helps in better understanding of pedestrian-vehicle interactions and the effect of location type on pedestrian safety. The crossing speeds of pedestrians were calculated using the distance covered by the pedestrians to cross the road and the time of crossing (by excluding the waiting time of pedestrians). The average values were taken for different pedestrian attributes and are shown in (**Table 5**) below.

Location	Pedestrian attribute	Pedestrian crossing speeds (m/s)				
		Minimum	15th percentile	50th percentile	85th percentile	Maximum
Intersection	Male	0.84	1.01	1.17	1.34	1.81
	Female	0.74	0.95	1.09	1.24	1.45
	Young	0.80	0.96	1.12	1.30	1.60
	Middle	0.79	0.98	1.17	1.35	2.02
	Old	0.76	0.83	1.01	1.2	1.42
Midblock	Male	0.68	0.90	1.22	1.71	2.10
	Female	0.65	0.93	1.15	1.54	2.02
	Young	0.60	0.87	1.19	1.62	1.97
	Middle	0.89	0.90	1.24	1.79	2.40
	Old	0.73	0.76	1.02	1.51	1.84

Table 5: Average pedestrian crossing speed at intersections and mid-blocks

The minimum crossing speeds of pedestrians were higher at uncontrolled intersections compared to mid-blocks and the maximum speeds were higher at mid-blocks. Higher vehicular speeds at midblock locations were the reason for higher crossing speeds. The male pedestrians were trying to cross the road with higher crossing speeds compared to female pedestrians at both midblock and uncontrolled intersections. 50th and 85th percentile crossing speeds of pedestrians were higher in the case of mid-blocks compared to intersections.

At both uncontrolled intersection and midblock locations, maximum gaps were accepted by female and old age pedestrians and lower gaps were accepted by male and middle age pedestrians. The critical gap for the pedestrian is the gap between two vehicles above which safe road crossing of the pedestrian is possible. Raff's method was used to find the critical gap. Percentage cumulative gaps on the y-axis and gap size on the x-axis were plotted and the intersecting point of gap accepted and rejected was taken as the critical gap. A critical gap of a pedestrian for mid-blocks and uncontrolled intersections were shown in the below (**Figure 6**)(a) and (**Figure 6**)(b). Critical gap at an uncontrolled intersection (2.90 seconds) was observed to be higher than the midblock location (2.20 seconds). This will be due to the higher vehicular speeds at the midblock location.



(a) (b)

Figure 6: Critical gap at (a) Midblock location (b) Uncontrolled intersection

Pedestrian gap acceptance models were developed for both midblock location and uncontrolled intersection using the multiple linear regression (MLR) technique. In both cases, pedestrian age has a positive correlation and pedestrian gender, waiting time, and stages of crossing have a negative correlation with the pedestrian accepted gap size. Frequency of attempts (FOA) influence the accepted gap size only in the case of midblock locations whereas the frequency of disturbances (FOD) influences the accepted gap size only in the case of uncontrolled intersections. Both FOA and FOD have a positive correlation with the pedestrian accepted gap size.

5. Conclusions

The present study modelled the pedestrian gap acceptance behaviour at midblock and uncontrolled intersections and also compared the pedestrian gap acceptance behaviour at both locations under mixed traffic conditions. The multiple linear regression (MLR) model was used to model the pedestrian gap acceptance behaviour at the uncontrolled intersection and midblock locations. In both cases, pedestrian age has a positive correlation and pedestrian gender, waiting time, and stages of crossing have a negative correlation with the pedestrian accepted gap size. Kadali et al. (2013) found that pedestrian accepted gap size increases with the increase in waiting time but pedestrians will be frustrated with higher waiting time and try to cross the road at lower gap sizes. Higher gap sizes were observed in the case of female and old age pedestrians. Female and old age pedestrians will take less risk and wait for a sufficient gap between vehicles but male and young pedestrians will try to cross the road with more risk. Frequency of attempts (FOA) influence the accepted gap size only in the case of midblock locations whereas the frequency of disturbances (FOD) influences the accepted gap size only in the case of uncontrolled intersections. Random dispersion of the residuals around the horizontal axis from the residual analysis shows the more appropriateness of the linear regression model for both midblock and uncontrolled intersections. A lower value of RMSE and MAE indicates that the difference between observed gap size values and predicted gap size values will be less and shows a good correlation between the observed and predicted values.

Maximum accepted pedestrian gap sizes were observed at uncontrolled intersections. The critical gap at the uncontrolled intersection (2.90 seconds) was observed to be higher than the midblock location (2.20 seconds). The lower critical gap for pedestrians at midblock locations will be due to the higher vehicular speeds. The higher risk-taking behaviour of male pedestrians is the reason for higher crossing speeds and the crossing speeds of old pedestrians were observed to be higher due to the lower risk-taking behaviour. A higher approaching speed of vehicles at midblock locations is the reason for the higher crossing speeds of pedestrians.

The results showed that the pedestrian crossing behaviour was not the same at all the crossing locations and it changes with the type crossing location. This study is useful to compare the severity levels of pedestrian-vehicle interactions at various crossing locations. Also, the results can be used to improve the pedestrian infrastructure facilities for safer crossings. This study is limited to mid-blocks and uncontrolled intersections but a better understanding of pedestrian road crossing is possible with the inclusion of other crossing locations like signalized intersections, roundabouts etc.

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