Modeling Pedestrian Gap Acceptance at Mid-block crossings in India

Udit JAIN [a], Rishi BADERIYA [b], Ankit GUPTA [c]

[a] *Department of Civil Engineering, Indian Institute of Technology Roorkee, Uttarakhand-247667, India; Email: udit.iitr@gmail.com*
[b] *Department of Civil Engineering, Indian Institute of Technology Varanasi, Uttar Pradesh-221005, India; Email: rishi.baderiya.civ14@iitbhu.ac.in*
[c] *Department of Civil Engineering, Indian Institute of Technology Varanasi, Uttar Pradesh-221005, India; Email: ankit.civ@iitbhu.ac.in*

Abstract: Pedestrian gap acceptance is a complex phenomenon, especially at mid-block sections in Indian cities, where mixed traffic conditions prevail. In such conditions, several researchers have reported smaller accepted gap values indicating unsafe crossing conditions. It is essential to understand the various factors responsible for the smaller accepted gaps and develop models to predict the gap size in such conditions. Video-graphic data was collected at six different location s in two Tier-II cities of India – Bhopal and Indore. Pedestrian crossings were recorded to capture 13,281 vehicular gaps faced by pedestrians. Factors affecting gap acceptance were identified and a multiple linear regression (MLR) model was developed to predict the accepted gap size. Further, data was collected at two locations in Chandigarh to validate the developed model. The paper identifies the factors influencing gap size and proposes an MLR model to predict the accepted gap size.

Keywords: pedestrian, gap acceptance, mid-block, crossing, modeling, pedestrian safety

1. INTRODUCTION

Crossing a road at a mid-block section can be tricky under mixed traffic flow conditions. The pedestrian has to perceive the speeds of different category of vehicles moving in different lane. To make things further more complicated, motorists in India neither follow lane discipline nor do they yield for pedestrians waiting to cross the road. Amidst all these problems, pedestrians usually find themselves waiting for a safe gap to cross the road which leads to increase in the delay faced by them. Due to this, pedestrians tend to force their way into the traffic stream and accept small and insufficient vehicular gaps, thereby creating hazardous conditions for themselves as well as the vehicles. This behavior makes pedestrians vulnerable and prone to road crashes.

The highest number of fatalities in road crashes are pedestrians (MoRTH, 2015; Tiwari et al., 2000). 84 percent of road crash fatalities in Kota, India occurred at mid-block sections (Mohan et al., 2009). It is essential to study the pedestrian crossing behavior at such crash prone crossing locations and understand the factors influencing the pedestrian crossing decision. Gap acceptance is the decision which describes if the pedestrian chose to cross the road or not under the given traffic flow conditions. Gap acceptance has been studied and used by researchers and local agencies to develop policies for pedestrians ensure safer crossings in cities around the world (Jain and Rastogi, 2016a). This study focuses on pedestrian gap acceptance and gap size accepted by pedestrians and attempts to model the gap size accepted by pedestrians in Indian cities.

This paper is structured as follows: *Section 1* describes the problem and the need of the study. *Section 2* presents the background of the work done by researchers in the field of gap acceptance. *Section 3* describes the data collection and extraction process. The preliminary data analysis on pedestrian crossing speed and critical gap has been presented in *Section 4*. The models developed for gap size estimation are presented in *Section 5* and finally the conclusions and discussions based on this study are presented in *Section 6*.

2. BACKGROUND OF THE RESEARCH

Pedestrian gap acceptance has been studied by researchers all around the world to understand the pedestrian crossing behavior (Gupta and Pundir, 2015). A pedestrian's decision to cross the road or wait for a safer gap is quite complicated and is dependent on various factors like age, gender, comfort level and safety perception of each individual (Kadali and Vedagiri, 2013; Ishaque and Noland, 2008). Experimental studies have been carried out by researchers to find the effect of age, gender, gap size and vehicle speed on the crossing decision (Oxley et al., 1997; Lobjois and Cavallo, 2007; Jain et al. 2014, Gupta et al. 2016). It has been observed that male pedestrians tend to be more impatient and wait lesser while crossing a road as compared to female pedestrians (Khan et al., 1999; Tiwari et al., 2007). Other researchers have also reported that the male pedestrians have significantly higher crossing speed as compared to female pedestrians (Knoblauch et al., 1996; Rastogi et al., 2011; Varhelyi, 1998; Tarawneh, 2001). Jiangang et al. (2007) investigated the change in pedestrian crossing behavior with the change in crossing speeds.

Availability of safe gaps in the traffic stream is highly unlikely in the traffic flow conditions that prevail in Indian cities today. In such scenarios, pedestrians use various crossing tactics and tend to accept smaller gaps which may lead to road crashes (Jain and Rastogi, 2016b; Pawar and Patil, 2015; Chandra et al., 2014). The process of gap acceptance after rejection of several gaps is usually described using critical gap. Critical gap cannot be determined by field observations and is estimated by different methods using the observed values of accepted and rejected gaps. Some of the most commonly used methods for the estimation of critical gap are Raff's method and maximum likelihood method (Raff, 1950; Troutbeck, 2014; Brilon et al., 1999; Jain and Rastogi, 2017).

Several researchers have used mathematical modeling to understand and predict the gap acceptance. Researchers have reported that pedestrians prefer rolling gaps instead of a single large gap in the traffic stream (Brewer et al., 2006; Kadali et al., 2015). Researchers have used different techniques like discrete choice theory and artificial neural networks for developing gap acceptance models (Himanen and Kulmala, 1988; Sun et al., 2003; Das et al., 2005; Antonini et al., 2006; Yannis et al., 2010; Hunt et al., 2011; Kadali et al., 2015). These studies focused on the probability of pedestrian gap acceptance irrespective of the gap size accepted. However, in Indian conditions, the accepted gaps are much lower as compared to other developed countries (Jain and Rastogi, 2017; Jain and Rastogi, 2016b; Pawar and Patil, 2016, Kadali and Vedagiri, 2016; HCM, 2010; Brewer et al., 2006). It is essential to understand the factors affecting gap acceptance and model the accepted gap size for better understanding of the pedestrian behavior in mixed traffic conditions. This study focuses on modeling accepted gap size using behavioral characteristics of pedestrians as the independent variables. The data requirements and the preparation of data set for this study have been illustrated in the following section.

3. DATA COLLECTION AND EXTRACTION

The data requirements for gap studies are usually quite intricate. Gap sizes (accepted and all rejected gaps) faced by individual pedestrian have to be recorded. Behavioral characteristics like waiting time, crossing speed, age, gender, rolling behavior, group size, etc., also need to be recorded at the same time. To capture such microscopic data in the traffic stream is a challenging task in itself. To make things simpler, videography survey technique was adopted. Six different mid-block crossing locations were identified in Bhopal and Indore which are Tier-II cities in India. The description of the data collection locations is provided in Table 1.

Table 1. Description of data collection locations

City	Location ID	Location	Carriageway Width (m)	Adjacent Land Use
Bhopal	HMR	Hamidia Road	8.1	Mix land use
	RML	Rang Mahal	7.1	Mix land use
	DBC	DB City Road	6.9	Commercial
Indore	VJN	Vijay Nagar	9.0	Commercial
	BHK	Bhawar Kuawan	8.8	Mix land use
	TNP	Teen Puliya	8.3	Commercial

Video camera was mounted on a 15 feet high stand to capture the pedestrian crossing location and the corresponding vehicular traffic stream. Three traps of 10 meter each were marked on the road to calculate the vehicle speed and the gap size from the recorded videos. The data collection was carried out for two hours in the peak period or regular weekdays to avoid any bias in the data collection process. These videos were further processed in the laboratory and played on a large screen monitor for the data extraction process. To prepare the data set, the video was played several time moving each frame at a time providing a least count of 0.04 seconds for the videos which were processed at 25 frames per second. The snapshot of the frame by frame extraction process is shown in Figure 1.

Figure 1. Snapshot of the frame by frame extraction process

From each frame pedestrian demographic data comprising of pedestrian gender, age and group size was recorded. For each pedestrian, the accepted and rejected gaps in the traffic stream were recorded. The extracted gap data consisted of total 13,281 gap data points recorded at midblock crossings sections. The data extracted from the video included the number and size of gaps accepted and rejected by pedestrians, waiting time, crossing time, crossing speed, rolling behavior, type of vehicle, gender, age and pedestrians group size. The preliminary data analysis on pedestrian speed and critical gap is presented in the next section.

4. PRELIMINARY DATA ANALYSIS

In the 13,281 gap data points recorded during data extraction, behavioral characteristics and accepted gaps of 2,616 pedestrians were captured in the two cities. The pedestrians were classified on the basis of age and gender to observe the demographic variation in pedestrian characteristics. Pedestrians moving together in groups of three or more were also observed separately. The number of pedestrians observed for this study are summarized in Table 2. The pedestrian characteristics like waiting time, crossing speed and gap sizes have been presented in the subsequent sub-sections.

Table 2. Summary of pedestrians observed for the study

City	Number of Pedestrians						
	Males	Females	Children	Adult	Elderly	Groups	Total
Bhopal	947	211	62	970	126	321	1,158
Indore	925	533	75	1,318	65	594	1,458
Total	1,872	744	137	2,288	191	915	2,616

4.1. Pedestrian Characteristics

The mean waiting time and crossing speed were calculated from the extracted data. These have been summarized in Table 3.

Table 3. Summary of pedestrian characteristics

Characteristic	Males	Females	Children	Adult	Elderly	Groups
Mean Waiting Time (sec)	3.42	4.50	3.04	4.21	6.96	4.58
Mean Crossing Speed (m/s)	1.32	1.14	1.51	1.22	0.99	1.14
Standard Deviation (Speed)	0.60	0.39	0.52	0.49	0.33	0.40
15th Percentile Speed (m/s)	0.83	0.77	1.06	0.81	0.71	0.78
85th Percentile Speed (m/s)	1.76	1.52	1.93	1.68	1.31	1.56

It was observed that female pedestrians waited longer as compared to male pedestrians and elderly pedestrians waited the most before crossing the roads. Similar variations in waiting time based on age and gender were observed by Khan et al. (1999) and Tiwari et al. (2007). The waiting time in groups was observed to be a little more than the average adult waiting time. It indicates pedestrians are more cautious while crossing in groups. Similar variations were observed in the mean crossing speed as well. Male pedestrians were observed to be more aggressive while crossing the road while elderly pedestrians crossed with the lowest speeds among all categories. The crossing speeds in groups was lesser than the average adult speed, which again indicates cautious crossing behavior in groups. The 15th percentile speeds used for the design of pedestrian facilities were found to be similar to the speeds observed by other researchers in India (Rastogi et al., 2011).

4.2. Critical Gap

In the study, if the lag was not accepted by a pedestrian, there was a single value of accepted gap and one or more values of rejected gaps for each pedestrian. These were also classified on the basis of age and gender and further processed for the estimation of critical gap. The gap sizes observed in this study have been summarized in Table 4. Critical gap has been estimated using Raff's method which is the most widely used method for the estimation of critical gap (Raff, 1950; Brilon et al., 1999; Jain and Rastogi, 2017). The cumulative distribution of accepted gaps and reverse cumulative distribution of rejected gaps were plotted. The point of intersection representing the critical gap by Raff's method was identified from the graph presented in Figure 2. Similar graphs were plotted for all categories of pedestrians to estimate the critical gap presented in Table 4.

Table 4. Summary of observed gap sizes

Gap Size	Males	Females	Child	Adult	Elderly	All Pedestrians
Mean Accepted Gap (sec)	4.13	4.36	3.77	4.21	4.90	4.29
Mean Rejected Gap (sec)	2.07	1.83	1.72	1.95	1.96	1.89
Critical Gap (sec)	3.53	3.36	3.15	3.51	3.91	3.49

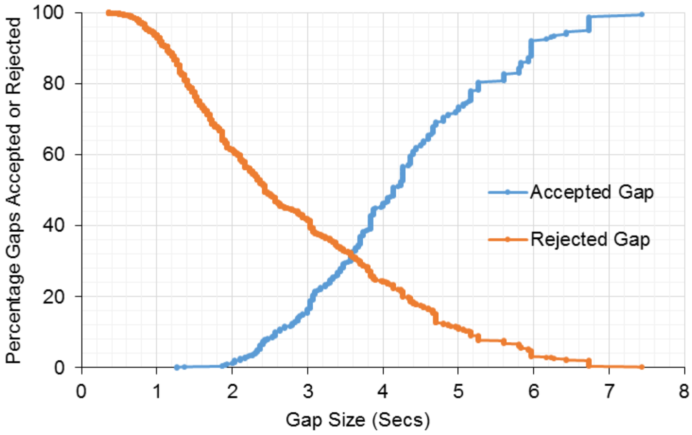

Figure 2. Critical gap estimation for all pedestrians by Raff's method

As expected, the critical gaps estimated in this study were found to be between 3 to 4 seconds. These values are similar to the critical gaps estimated by other researchers in India (Jain and Rastogi 2017; Jain and Rastogi, 2016b; Pawar and Patil, 2016, Kadali and Vedagiri, 2016).These values are much lower than the critical gaps observed in developed countries like USA and UK (HCM, 2010; Brewer et al, 2006). The lower values of critical gap indicate the risk taking behavior of pedestrians in Indian cities. The low values of critical gap are a result of different types of vehicles moving at different speeds and non-yielding motorists driving without lane discipline. Such conditions add to the vulnerability of pedestrians at crossing locations and it is essential to understand the factors affecting the low values of gap size. The next section explores the various factors affecting gap acceptance and attempts to model the accepted gap size of pedestrians.

5. GAP ACCEPTANCE MODEL

The various pedestrian and vehicle characteristics recorded during the data collection process were considered for the development of gap acceptance model. These characteristics were in the form of both discrete and continuous variables. These factors have been tabulated and described in Table 5.

Table 5. Factors considered for model development

Variable	Type of Variable	Unit	Description
Gap Size	Continuous	seconds	Time gap between the tail of the leading vehicle and head of the following vehicle
Waiting Time	Continuous	seconds	Time for which a pedestrian waits before crossing the road
Crossing Time	Continuous	seconds	Time taken by pedestrian to cross the road
Crossing Speed	Continuous	m/s	Speed of a pedestrian while crossing the road
Gender	Discrete	0 –Female 1 - Male	Male or female
Age Group	Discrete	0 - Elderly 1- Adult 2 - Young	Elderly (>60 years) Adult (18-60 years) Young (<18 years)
Pedestrian Group	Discrete	0 – Single pedestrian 1 - Group	Group is three or more pedestrians crossing the road together
Rolling	Discrete	0 - No 1 - Yes	Rolling is accepting multiple small gaps in one crossing with lateral movements along the road to find an acceptable gap
Gap Acceptance	Discrete	0 - Rejected 1 - Accepted	Acceptance or rejection of the available gap
Type of Vehicle (PCU)	Discrete	0.50 - Two Wheeler 0.75 - Three Wheeler 1.00 - Car 3.00 - Heavy vehicle	Vehicle categories

The multiple linear regression technique (MLR) was used for predicting the accepted gap size of pedestrians. Gap size was found to be following a lognormal distribution. Logarithmic transformation of gap size was carried out to ensure it followed a normal distribution. The general MLR model equation for estimating the minimum accepted gap is given below. Here, log-gap is taken as the dependent variable and other factors have been considered as the explanatory variables.

$$Ln(Gap) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots \dots \dots \dots + \beta_n x_n \quad (1)$$

where,

Ln(Gap) : log of accepted gaps

x_i : explanatory variables

β_i : coefficients of the explanatory variables
β_o : constant

The correlation matrix was developed to check the correlation between each pair of variables. The variables having a strong correlation with gap size were selected for the first stage of model development. The explanatory variables which were having correlations among each other were removed one by one using trial and error method to eliminate the problem of multicollinearity in the model. The statistical summary and significance checks of the exploratory variables used in the gap size model at 95 percent confidence level are presented in Table 6.

Table 6. Statistical summary of the model

Parameter	*coeff*	*std err*	*t stat*	*p-value*	*lower*	*upper*
Intercept	5.056	0.205	24.625	0.000	4.653	5.459
Waiting Time (WT)	-0.023	0.009	-2.512	0.012	-0.041	-0.005
Crossing Speed (CS)	-0.451	0.096	-4.716	0.000	-0.638	-0.263
Rolling (ROL)	-0.346	0.101	-3.43	0.001	-0.544	-0.148
Gender (GEN)	-0.246	0.121	-2.043	0.041	-0.483	-0.01
Age Group (AG)	-0.282	0.132	-2.143	0.032	-0.54	-0.024
Vehicle Type (PCU)	0.546	0.068	8.011	0.000	0.412	0.68

The model predicts the minimum accepted gap size for pedestrians based on behavioral and demographic characteristics of pedestrians at 95 percent confidence level. The overall statistical significance of the model was checked using the *F-RatioTest* or the *F-Test.* The *F-sig* value was found to be 0.000 (*p-value*< 0.05) indicating a statistically significant model fit at 95 percent confidence level.

The MLR model regression coefficient of determination, R-square was found to be 0.68. It means that only 68 percent of the variation in the accepted gap size is explained by the selected explanatory variables. The adjusted R-square for the model was found to be 0.686. This indicates that there will not be much change in R-square value by adding new explanatory variables to the model.

It can be inferred from the coefficients of the regression analysis and their corresponding *p-values* that vehicle type, pedestrian crossing speed and rolling behavior were the most significant factors affecting accepted gap size. Negative sign for the coefficients of crossing speed and waiting time indicates that as the crossing speed and/or waiting time increases the size of gap accepted by pedestrian decreases. This indicates that as the waiting time increases due insufficient gap size in the traffic stream, pedestrians increase their speed and tend to accept smaller gap sizes, as observed in the preliminary analysis. The model also indicates that as the as the accepted gap size decreases, rolling behavior comes into play. Pedestrians roll between multiple small gaps rather than wait for a single long gap for crossing the road. The coefficient of the vehicle type signifies that the accepted gap size increases with the increase in the size of the vehicle.

For the purpose of validation, data was collected at two locations - Sector17 bus terminal and Sukhna Lake in Chandigarh, India. Data extraction was carried out and a data set of 3,855 gap data points was prepared. The proposed model was tested against the same set of extracted variables. The Root Mean Square Error (RMSE) and R-square for the prediction model was found to be 1.73and 0.61 respectively. The RMSE indicates the standard deviation of the unexplained variables. It means that the residuals are 1.73 times standard deviation away from the regression line.

6. CONCLUSIONS AND DISCUSSION

This paper focused on understanding pedestrian behavioral and demographic characteristics and their effect on accepted pedestrian gap size. It was observed that the waiting time and crossing speeds varied across age and gender as reported by other researchers as well. For the purpose of uniformity in policy formulation across different age groups and gender, the number of pedestrians should be converted into Equivalent Adult Units (EAU). EAU is to pedestrians as PCU is to vehicles. EAU is widely used in United Kingdom for the formulation of pedestrian policies and pedestrian crossing warrants. It helps in providing better pedestrian facilities depending upon the proportions of young, adults and elderly in the mix of pedestrians. Further research can be carried out for the formulation of EAU values with respect to pedestrian behavior and characteristics in mixed traffic conditions.

Preliminary analysis also revealed that as compared to developed countries, the accepted gap and critical gap values were found to be much lower for pedestrians in India. These lower values of gap indicate the risk taking behavior of Indian pedestrians in mixed traffic conditions. Accepting insufficient gap sizes by increasing the crossing speed creates hazardous conditions for both pedestrians as well as vehicles. Exploratory analysis was carried out to identify the factors affecting accepted gap size. It was observed that crossing speed, rolling and vehicle type had the most significant effect on the accepted gap size. Other significant factors were waiting time, age group and gender. A multiple linear regression model is proposed in this study which predicts the gap size accepted by pedestrians based on their demographic and behavioral characteristics. The model was found to be statistically significant and was validated using data from two different pedestrian crossing locations in Chandigarh.

This study was limited to pedestrian crossings at mid-block locations in Indian cities. The proposed model has been developed based on pedestrian and traffic characteristics observed in India. These characteristics may vary from country to country and therefore, the proposed model should be tested and calibrated before it can be used in any other traffic flow conditions. However, the methodology for the development of the gap model and the factors affecting gap acceptance are universal in nature. Further studies may be carried out to predict the probability of gap acceptance using discrete choice models, fuzzy logic or artificial neural networks. The finding of this study can be useful for researchers, academicians, traffic engineers and policy makers. The study can be further extended for the formulation of policies and selection of appropriate pedestrian crossing facilities to ensure safe and efficient crossing movements of pedestrians at mid-block crossing location.

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