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Modelling pedestrian road crossing behaviour under mixed traffic condition

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Abstract

Pedestrian road crossings have become a major issue in road traffic flow, especially in urban areas where there is no controll for pedestrian road crossings. Pedestrian road crossing behaviour is a serious threat to pedestrians at uncontrolled midblock crossing locations in the mixed traffic conditions. Due to increase in motor vehicle growth there is an increase in the regulation of motor vehicles only and the regulation of pedestrian is completely neglected. This increases the uncontrolled road crossing behaviour of pedestrian. The main motivation of this study is to investigate the pedestrian road crossing behaviour at the uncontrolled midblock location in India under mixed traffic condition. Pedestrian road crossing behaviour at uncontrolled midblock has been modeled by the size of vehicular gaps accepted by pedestrian using multiple linear regression (MLR) technique. Also choice model has been developed to capture the decision making process of pedestrian i.e., accepted or rejected vehicular gaps based on the discrete choice theory. Suitable study stretch, which a four lane divided urban arterial in Hyderabad, India, was selected for data collection. The collected data consists of 4198 gap data points which include both accepted and rejected vehicular gaps. Pedestrians' road crossing behaviour has been explained in terms of minimum gap acceptance value by using a rolling gap (pedestrian roll over the small vehicular gaps). It has also been explained by the binary logit model with the help of vehicular gap size, frequency of attempt and rolling gap. The study concludes that the pedestrian behavioural characteristics like the rolling gap, driver yielding behaviour and frequency of attempt plays an important role in pedestrian uncontrolled road crossing. These inferences are helpful for pedestrian facility design and controlling pedestrian safety issues at uncontrolled crossings.

Keywords: Pedestrian, road crossing behaviour, gap acceptance, mid-block, mixed traffic condition

1. Introduction

Due to the increase in economic growth of the country, there has been rapid urbanization and increase in traffic growth in Indian cities. It has resulted in increase in urban sprawl and further resulted in increase in the use of public transportation trips. Public transportation trips are usually connected to walk trips either origin or destination or both and sometimes at mode transfer points. A pedestrian may need to cross the road for many reasons. Due to their urgency or value of time, pedestrian follow non-

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complaint behaviour while crossing the road. The traffic on the roads of Indian cities is highly heterogeneous in nature encompassing vehicles with a wide range of static and dynamic characteristics. There are more than ten different types of vehicles present in the traffic on major roads of Indian cities. All these different types of vehicles move on the same road space occupying any position on the road depending on availability of free space at a given instant of time without complying to any lane discipline. This heterogeneity in traffic and jaywalking behaviour of pedestrian leads to severe conflicts with motorized vehicles and results in a decline of pedestrian safety. This complexity of interactions between pedestrian and vehicular traffic increases mostly at uncontrolled mid-block and unsignalised intersections.

A study carried out by IIT Delhi and university of Michigan shows that urban road traffic accidents have been increasing at about 8% annually and most of the (60%) victims are pedestrians and 85% of these fatalities occur at mid-block locations (Mohan et al., 2009). A Ministry of Urban Development (MOUD) study found that pedestrian share in road accidents is 19% in Hyderabad (MOUD, 2008). Another recent Indian study found that 54% accidents are related to the road crossing activity (Kumar and Parida, 2011). All these study statistics clearly shows that pedestrian safety is a main issue for transport planners, traffic engineers and policy makers. Hence, it is worth studying the road crossing behaviour of pedestrians in mixed traffic condition at uncontrolled mid-block location. This study is an attempt in this direction. The organization of this research paper is as follows: Section 1 is a brief introduction of importance of pedestrian road crossing behaviour at the uncontrolled midblock location; Section 2 describes the background about the pedestrian crossing behaviour. In section 3, an overview of the site characteristics and the data collection process is presented. Section 4 presents the pedestrian road crossing behaviour models developed in this study. Section 5 describes the model results and discussion. The conclusions are summarised in Section 6.

2. Background of the research

There have been several studies carried out to understand the pedestrian behaviour, which are influenced by different factors such as pedestrian perception, roadway and environmental characteristics etc. In general, pedestrian trip can be identified as a series of decisions from the strategic level to the operational level, each affecting subsequent choices. As the decision is made whether to walk or not at strategic level, a decision of choosing either crossing at the intersection or mid-block is made at tactical levels and change of behaviour is obtained at final stage at operational level (Daamen, 2004). At the strategic level, there have been a number of studies to estimate whether walking activity is performed by pedestrian after arriving at the road side. It has been reported that this is mostly influenced by the pedestrian facilities, comfort, convenience, connectivity with other modes and roadway environmental characteristics (Shay et al., 2006; Iacono et al., 2010). Sudden decisions are made at the tactical level in order to accomplish the set of choices made at the strategic level. There are numerous models available for route choice, which represents the choice made at the tactical level (Timmermans et al., 1992; Sisiopiku and Akin, 2003). The route choice models basically consider walking distance and time which are integrated with crossing models. Individuals' judgement about when and where to cross the road are very complex and are normally represented by various factors such as comfort, convenience, ease of crossing and safety. If the pedestrian decides to walk, then they cross the road somewhere on midblock and pedestrian behaviour changes dynamically. Pedestrians continuously change their actions with respect to environmental characteristics. Several researchers have attempted to identify factors influencing pedestrian behaviour including sudden decisions that affects pedestrian walking characteristics such as choice to accelerate or decelerate walking speed, stop or wait and where to cross a street (Ishaque and Noland, 2008).

Earlier studies provide significant facts about pedestrian demographic characteristics (such as age, gender) and how these characteristics influence road crossing behaviour. Such studies have focused on detailed experiments to find out the effect of age on road crossing decisions with effect of vehicle distance or speed of vehicle (Oxley et al., 1997; Lobjois and Cavallo, 2007). Most of these studies have been carried out in a virtual environment. Road crossing behaviour with respect to gender has also been observed in various studies. Males have a tendency to show more hazardous road crossing behaviour than females due to less waiting time (Khan et al., 1999; Tiwari et al., 2007). Few studies have also explored the importance of the pedestrian speed at different locations (Knoblauch et al., 1996; Rastogi et al., 2011), such as the zebra crossing location (Varhelyi, 1998) and signalized intersections (Tarawneh, 2001). Outline of these studies suggest that males walk significantly faster than females while crossing the roads. A recent study was focused on legal versus illegal pedestrian road crossing behaviour at mid-block location in China (Cherry et al., 2012). Few studies have identified pedestrian behaviour in mixed traffic streets and developed a micro-simulation model in order to find out the fundamental characteristics as well as the conflicts of the pedestrian movement (Shahin, 2006). A study in Beijing, investigated pedestrian behaviour and traffic characteristics at un-signalized midblock crosswalk. Authors have explained the pedestrian speed change condition with pedestrian behaviour (Jiangang et al., 2007). Some studies have also addressed pedestrian road crossing behaviour by considering the effectiveness of educational training programs (Dommes et al., 2012). Studies had identified the importance of the environmental characteristics, such as type of crossing facility, traffic volume and roadway geometry on road crossing behaviour. Some studies have also explored the pedestrian road crossing behaviour before and after re-construction of traffic facility (Gupta et al., 2010).

Gap can be defined as the time difference between leader vehicle and lag vehicle and it is an important term in pedestrian road crossing behaviour. The availability of larger gaps in traffic stream is very rare, so the behaviour of pedestrian varies with availability of small gaps and they try to accept smaller gaps with tactical behaviour. In this process, the critical gap (the minimum average gap length that is accepted by half of all pedestrians to cross the road safely) plays a major role. Pedestrian gap acceptance behaviour is affected by several factors and it is also important from safety point of view. On this line, few studies have explored pedestrian road crossing behaviour with help of gap acceptance criteria. Some studies have also explored the pedestrian gap acceptance behaviour with behavioural and statistical analysis. 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. Statistical analyses have revealed that 85th percentile accepted gap is 9.4 s (Brewer et al., 2006). Mathematical models have also been developed to explore the pedestrian gap acceptance behaviour at different locations (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 and Vedagiri, 2013). Most of these mathematical modelling techniques include binary logit model based on the discrete choice theory. A few studies have also been carried out at un-controlled intersections to explore the interaction between motorists and pedestrians (Ibrahim et al., 2005).

Numerous studies have explored the pedestrian safety issues at different locations. The self-reported road crossing behaviour of pedestrians in relation to beliefs and normative motives with safety rules are addressed in some studies (Yagil, 2000). Studies had focused on the safety impacts of marked and unmarked crosswalks for pedestrian and driver in rural and recreational areas (Mitman et al., 2010). The injury severity of pedestrians in motor-vehicle crashes has been analysed by using a heteroskedastic generalized extreme value model (Kim et al., 2008). Some studies explored the pedestrian road crossing behaviour and safety issues at unmarked location (Zhuang and Wu, 2011). Studies have also explored pedestrian behaviour in narrow urban streets with mixed traffic condition and a new concept for level-of-service standards has been developed (Kwon et al., 1998). Researchers have also explored the pedestrian road crossing behaviour with effect of pedestrian demographic as well as gap acceptance criteria. However, no studies are available for pedestrian behavioural characteristics which is more important than demographic as well other environmental characteristics in mixed traffic conditions. Research on pedestrian vehicle interaction and pedestrian road crossing behaviour at an uncontrolled midblock location in urban environments are more important to identify hazardous locations for pedestrians. In this context, the primary objective of this study is to describe the road crossing behaviour of pedestrian at un-controlled midblock location. In particular the study focuses on the behavioural characteristics of pedestrian with the help of multiple linear regression (MLR) and binary logit (BL) models.

3. Methodology

The major steps involved in this study are: (1) selection of suitable site for field survey (2) field data collection and extraction (3) analysis of pedestrian demographic characteristics and pedestrian behavioural aspects (4) model development for pedestrian road crossing behaviour.

3.1 Site selection

The selected site is an uncontrolled (unmarked and no right of way to the pedestrian) mid-block location and two lane per direction two way road in Hyderabad, India. The snapshot of study section is shown in Figure 1. The selected mid-block section is 135 m away from the signalised intersection. It has an adequate volume of pedestrians as well as vehicular traffic to allow for collection of pragmatic behavioural data using video graphic survey.

3.2 Data collection and extraction

Videography survey was conducted on 21st December 2011 at the selected mid-block location during the working day in normal weather conditions. The video camera was placed on the roof of a building. The video camera viewed a total of 40 m length along longitudinal direction, out of this only 15 m (which is marked in the Figure 1) is used for data collection where the pedestrians are usually crossing the road. In this study it has been observed that because of high traffic flow, realistic lag (first gap) could be obtained based on the coverage length (40 m) of video graphic survey. The video was captured and thirty JPEG files were obtained from each second of video recording with the help of Snapshot Wizard software. From each snapshot, pedestrian demographic data have been collected which includes pedestrian gender, age and platoon size. The average observed vehicular traffic during the survey at study location was 4722 vehicles per hour and the mean speed of vehicular traffic was 24.28 kmph which were calculated based on the analysis of the video data.

Figure 1. Photograph of study location in Hyderabad, India.

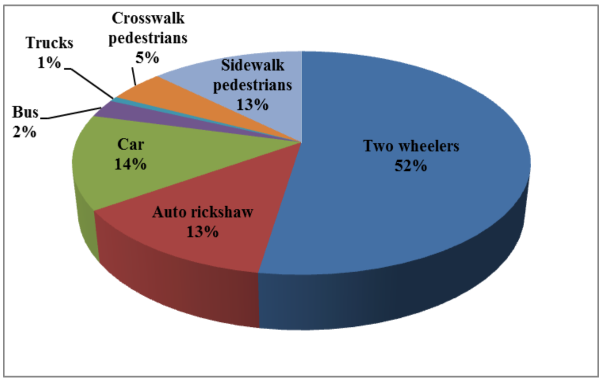

Figure 2. Mode split at study location, India.

Figure 2 shows the composition of vehicular traffic and pedestrians. The crossing pedestrians constitute about 5% of the total modal split observed during survey time in Hyderabad, India. The percentage of bicycle is negligible at this location and hence not included in the modal split. The vehicular gap, vehicular characteristics (vehicle type and speed of the vehicle) and pedestrian behavioural characteristics were collected directly in running video at an accuracy of 1 in 30 sec (0.033 s) with the same software. The extracted data consisted of 4198 (accepted/rejected) gap data points at un-controlled midblock location. In this study, vehicular gaps were collected when a vehicle intersects the perpendicular path of pedestrian which is assumed as an imaginary line from their current position to the opposing sidewalk.

3.3 Demography and pedestrian behavioural characteristics

The pedestrian demographic characteristics comprises of gender, age groups (i.e., < 15 years-children, 15-30 years-young, 30-50 years-middle aged and > 50 years-elders) by visual appearance. Also the data collected from video observation contains waiting time and gap acceptance condition. Pedestrians' and drivers' behavioural data were extracted from the video. In this study, the pedestrian rolling gap is the one of the important parameter influencing pedestrian behaviour. Pedestrians are rolling over the small vehicular gap which is characterised as rolling gap as depicted as path A-A in Figure 3. It is a usual pedestrian behaviour in mixed traffic condition in developing countries. From the field, it has been observed that drivers are more unlikely to yield to pedestrians waiting at curbs. So, in this study driver yielding behaviour is considered as whether they stop or reduce speed or change the vehicular path while a pedestrian is in the middle of the crossing. After arriving at the curb, most of the pedestrians may look at the traffic to check the suitable gap for crossing the road. The duration and number of times (frequency) they are checking available gaps in traffic affect the pedestrian gap acceptance behaviour. So, the following pedestrian behavioural aspects have been observed from the video: observation duration at curb or median (duration of time spent by a pedestrian at curb or median during traffic flow for suitable gap acceptance), number of observations at curb or median (number of observations made by a pedestrian at curb or median during traffic flow for suitable gap acceptance), observation duration while crossing (duration of time spent by a pedestrian while crossing during traffic flow for accepting gap), number of observations while crossing (number of observations made by a pedestrian while crossing on traffic flow for accepting gap). Particularly these behavioural data were collected from the video at an accuracy of 1 in 30 sec (0.033 s) using Snapshot Wizard software. Special care was taken while extracting the recorded data that congested traffic flow conditions were completely eliminated. This set of behavioural data provided a good indication of the amount of interaction between pedestrians and vehicular traffic. The collected data are summarised in Table 1 with details.

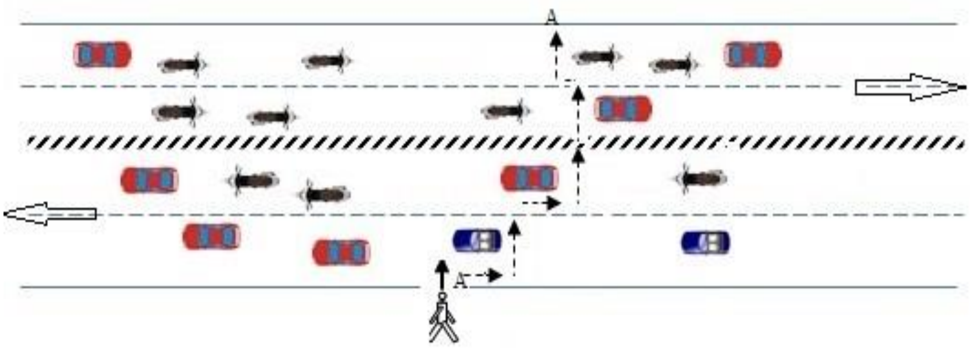

Figure 3. Pedestrian rolling gap movement.

Table 1 The collected variables

Variable	Type of variable	Unit or Code	Description
Gap size	Continuous	Time in sec	Time gap between two vehicles with reference to crosswalk point.

Variable	Type of variable	Unit or Code	Description
Waiting time	Continuous	Time in sec	Time spent at the curb or median for suitable gap.
Vehicle speed	Continuous	Kmph	Speed of the vehicle at crosswalk area.
Pedestrian speed	Continuous	m/sec	The speed of the pedestrian while crossing the road.
Frequency of attempt	Continuous	Number	Number of attempts a pedestrian makes to accept the vehicular gap.
Frequency of disturbance	Continuous	Number	Number of times the vehicle moving on the paved shoulder (pedestrian standing area) caused disturbance to pedestrian.
Observation duration at curb or median	Continuous	Time in sec	Duration of time spent by a pedestrian at curb or median for accepting suitable gap.
Observation duration while crossing	Continuous	Time in sec	Duration of time spent by a pedestrian for accepting gap while crossing the road.
Number of observations at curb or median	Continuous	Number	Number of observations made by a pedestrian at curb or median on traffic flow for accepting suitable gap.
Number of observations while crossing	Continuous	Number	Number of observations made by a pedestrian while crossing on traffic flow for accepting gap.
Gender	Discrete	0-Women; 1:Man	Male or female.
Age	Discrete	0:Elders 1:Middle 2:Young	By visual appearance.
Pedestrian platoon	Discrete	0:Single 1:Two 2: More than two	Number of pedestrians in the group.
Gap Type	Discrete	0:Near 1:Far	Whether the gap is close to the curb or median.
Pedestrian speed change	Discrete	0-No; 1:Yes	Whether a pedestrian changes speed while crossing the road.
Pedestrian crossing path change	Discrete	0-No; 1:Yes	Whether a pedestrian changes crossing path while crossing the road.
Pedestrian rolling gap	Discrete	0-No; 1:Yes	Whether pedestrian rolls over the available small gaps.
Pedestrian baggage effect	Discrete	0-No; 1:Yes	Whether pedestrian is carrying baggage or not.

Variable	Type of variable	Unit or Code	Description
Type of vehicle	Discrete	0:Heavy 1:Car 2: 2W; 3: 3W	Type of vehicle.
Driver behaviour	Discrete	0-No; 1:Yes	Whether the driver reduces speed or changes their vehicular path, when pedestrian is already on the carriageway.
Accepted lag or gap	Discrete	0-Lag; 1:Gap	Whether the pedestrian accepts the lag (first vehicular gap) or successive gaps.
Gap acceptance	Discrete	0:Rejected 1:Accepted	Whether a pedestrian is accepting gap or rejecting.

3.4 Model framework

The effect of selected variables on the pedestrian road crossing behaviour at uncontrolled mid-block location is modelled with the help of multiple linear regression technique. In this model, the minimum accepted vehicular time gap size by pedestrian was estimated with pedestrian behavioural characteristics. The probability of accepting vehicular time gap was modelled with discrete choice model technique. In discrete choice models, instead of increase or decrease in gap value like in MLR model, it is regressing for the probability of a categorical outcome. In simplest form, it means that considering a binary outcome variable i.e., pedestrian accepts available gap or rejects in terms of probability. The behaviour of the pedestrian can be predicted by choices made with different available gaps with the binary logit model by discrete choice modelling technique. In both the models, the functional relationship between input and output variables can be easily represented.

3.4.1 Multiple Linear Regression model (MLR model)

The MLR model is useful for finding out the accepted gap size for pedestrians. The minimum pedestrians' gap acceptance value is represented by a regression model. The collected vehicular gap data is with an accuracy of 0.033 second. The pedestrian may reject more number of available small gap size values and they may accept higher gap size values. To develop the minimum gap acceptance model, a log normal regression was selected by considering that pedestrian accepted gaps which followed a normal distribution. The accepted gap sizes are best fitted by a normal distribution by considering logarithm of the gaps. The general model framework is given below:

$$\text{Log-Gap} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots\ldots\ldots\ldots + \beta_n X_n \quad (1)$$

Where
Log-Gap= logarithm of accepted gaps; Xi-n= explanatory variables;
$\beta_{1\text{-}n}$= are estimated parameters from the model; β_0= constant

3.4.2 Binary Logit Model (BL Model)

In this study, the pedestrian decision making condition is described by the binary logit model (BL Model). The probability of selecting an alternative (accept/reject) is based on a linear combination function (utility function) expressed as:

$$U_i = \alpha_i + \beta_{i1} X_1 + \beta_{i2} X_2 + \beta_{i3} X_3 + \beta_{i4} X_4 + \ldots\ldots\ldots\ldots\ldots + \beta_{in} X_n \quad (2)$$

Where
U_i=the utility of choosing alternative i; i= the alternative (accept/reject)
n= number of independent variables; α= constant; β = coefficients
The utility of alternative 'i' has to be transformed into a probability in order to predict whether a particular alternative will be chosen or not. The probability of choosing alternative 'i' is then calculated using the following function:

$$P(i)=1/\ [1+ \exp(-U_i)] \quad (3)$$

4. Pedestrian crossing behavioural models

4.1 MLR model

Table 2 MLR test results

Variable	β_i (Coefficient)	Standard error	*t-value*	*p-value*
Constant (β_0)	0.752	0.035	21.635	0.000
Driver yield behaviour (DYB)	-0.128	0.011	-11.905	0.000
Pedestrian rolling gap (Rgap)	-0.124	0.016	-7.988	0.000
Frequency of attempt (Fatm)	-0.066	0.019	-3.377	0.001
Accepted lag or gap (LagGap)	0.054	0.019	2.869	0.005
Age	-0.031	0.010	-3.180	0.002
number of observations while crossing (NOWC)	-0.029	0.013	-2.231	0.027
Frequency of disturbance (FD)	0.012	0.006	2.085	0.038
Vehicle speed (VS)	0.003	0.001	2.864	0.005

(Note: p-value and t-value are represented at 95% confidence interval)

Based on the results presented in Table 2, MLR equation can be rewritten as,

Log-Gap = 0.752 -0.128 * DYB -0.124 * Rgap + 0.054 LagGap – 0.066 * Fatm + 0.003 * VS – 0.031 * Age – 0.029 * NOWC + 0.012 * FD (4)

Lognormal regression model was developed using Statistical Package for the Social Sciences (SPSS 16.0) software package to find out the minimum accepted vehicular gap size due to pedestrian road crossing behaviour at uncontrolled mid-block location. To check the significance level on the minimum accepted vehicular gap size at 95% confidence interval, chi-square test was conducted for all the variables. It was found that waiting time and observation duration at curb or median $\chi 2$ - p values are 0.244 and 0.386 respectively and number of observations at curb or median $\chi 2$ - p values is 0.408 were not significant. In addition to this, gender and age are also not significant as the $\chi 2$

p values are 0.386 and 0.363 respectively (significance level considered with 95% confidence interval). A logarithm of the accepted gap size was considered as the dependent variable and the remaining variables are independent variables. The MLR model represents the minimum accepted gap value which includes significant explanatory variables at 95% confidence interval. This model represents a critical gap required for pedestrian to cross the road. The model calibration was considered with 75% data and remaining data was used for validation of the model. The calibrated R^2 value was found as 0.786. The descriptive statistics of MLR test, t and p-values are summarized in Table 2. Reported t-values and p –values are the statistical test values of each independent variable. The graph was plotted between observed (remain 25% data) and predicted values. It shows the validity of calibrated model and a valid R^2 value was found 0.782. Also the critical gap was estimated by Raffs method and it founded as 5.37 sec.

4.2 Binary Logit Model (BL Model)

To study the choice behaviour (accepted/rejected), a binary logit model (BL Model) was developed in NLOGIT 4 software and the choice opportunities for pedestrian road crossing behaviour has been analysed at uncontrolled mid-block location. The descriptive statistics of BL Model test are summarized in Table 3. The utility equation (5) is given for the probability of gap acceptance condition, i.e., U1 (i=1 for acceptance). The significance of the independent variable is considered with the effect of t-values and p –values. The model validation is carried out with success prediction table and the overall prediction accuracy was found as 98.7%. Hence, the proposed model is strong enough to predict the gap acceptance behaviour at uncontrolled mid-block location.

Table 3 Binary LOGIT model (BL Model) test results

Variable	β_i (Coefficient)	Standard error	*t-value*	*p-value*
Constant (α)	-13.310	2.4682	-5.393	0.000
Pedestrian rolling gap (Rgap)	7.207	1.021	7.056	0.000
Frequency of attempt (Fatm)	3.633	1.332	2.726	0.006
Vehicle speed (VS)	-0.312	0.0585	-5.329	0.000
Vehicular gap size (GSize)	4.359	0.561	7.770	0.000

(Note: p-value and t-value are represented at 95% confidence interval)

Based on the results presented in Table 3, BL model equation can be rewritten as,

$$\mathbf{U1} = -13.310 + 7.207 * Rgap + 3.633 * Fatm - 0.312 * VS + 4.359 * GSize \quad (5)$$

5. Model results and discussion

The pedestrian road crossing behaviour is quite unpredictable at uncontrolled mid-block location. Different pedestrian behavioural characteristics were considered for minimum gap size model, out of which only few (eight) variables could explain the pedestrian road crossing behaviour. Among the different variables driver yielding behaviour, rolling gap and vehicle speed are the most influencing variables. Variables such as waiting time, observation duration at curb or median, observation duration while crossing and number of observations at curb or median does not affect the pedestrian road crossing behaviour in this study. Whereas, number of observations while crossing is one of the significant variable and very useful while using the rolling gap. At mid-block locations pedestrians are accepting vehicular gap size without much waiting after arriving at the curb. They rely on rolling gap and driver yield behaviour. Due to the increase in use of rolling gap there is a decrease in pedestrian safety. Incidentally, rolling gap and driver yielding behaviour are highly significant factors in reducing the accepted gap size. It is also observed that the driver yielding behaviour does not have much effect on the pedestrians' waiting time at the curb and median. When pedestrian reaches the middle of the road it affects the pedestrian road crossing behaviour.

Generally, type or size of vehicle is an important factor for accepting the gaps (Yannis et al., 2010), but in this study it is observed that pedestrians are accepting vehicular gaps with respect to vehicle speed. This observation is strongly supported by recent study in mixed traffic condition in developing countries (Cherry et al., 2012). It is also true, because small vehicles may come with higher speeds. So, the pedestrian may not accept the available gaps with small vehicle in mixed traffic condition at higher speeds and sometimes heavy vehicle gaps may be accepted due to less speed. So due to this, speed of the vehicle plays important roles in both the models (MLR and BL models). Pedestrian age, frequency of attempting gap, number of observations while crossing, and frequency of disturbance are also important variables in MLR model for reducing gap size. If pedestrians accepts the lag (initial vehicle gap size), it represents the higher gap size than regular gap size.

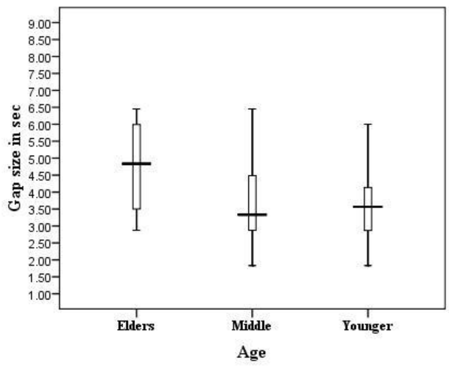

Figure 4. Mean accepted gap size for different age group of pedestrians

Pedestrian age is statistically significant for minimum gap size and there is a significant difference between elders and young pedestrian age groups, which can be observed in Figure 4. Also this figure shows the mean accepted gap size for different pedestrian age groups. It indicates that the pedestrian chooses small gap sizes with decrease in age at uncontrolled mid-block location, but there is not much difference between middle and young age groups. The mean accepted gap sizes in seconds for elders, middle and young age groups are 4.75, 3.35 and 3.504 respectively. The maximum and minimum accepted gap sizes in seconds for different age groups are 6.496 and 2.81 for elders, 6.49 and 1.79 for middle, 6.6 and 1.79 for young. It is also logical from the field data, that selecting the rolling gaps by young and middle age group is very high when compared to elders groups. So the rolling gap criteria makes the age as one of the important factor to reduce gap sizes at uncontrolled mid-block location.

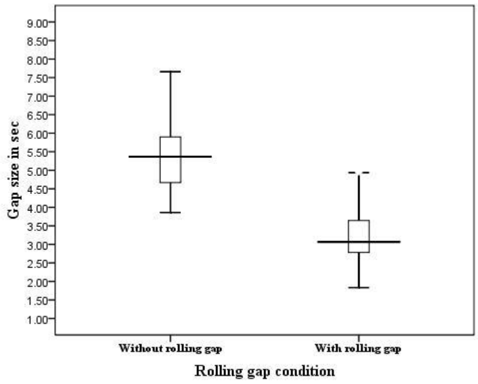

Figure 5. Mean accepted gap size under pedestrian rolling gap behaviour

Pedestrian rolling gap behaviour is the most important variable introduced in this study. While pedestrians roll over the gaps they choose small gap sizes and in this situation other pedestrian tactics (speed change condition, crossing path change condition etc.) also comes into picture. Figure 5 shows the pedestrian rolling gap behaviour with available vehicular gap size. The mean accepted gap sizes in seconds without rolling and with rolling gap are 5.38 and 3.05 respectively. It can be observed that there is a drastic change in mean accepted gap size when pedestrians use rolling gap. If pedestrians choose rolling gap they are more likely to accept the minimum gap sizes. Hence, it is a statistically significant variable for the minimum gap size in the MLR model.

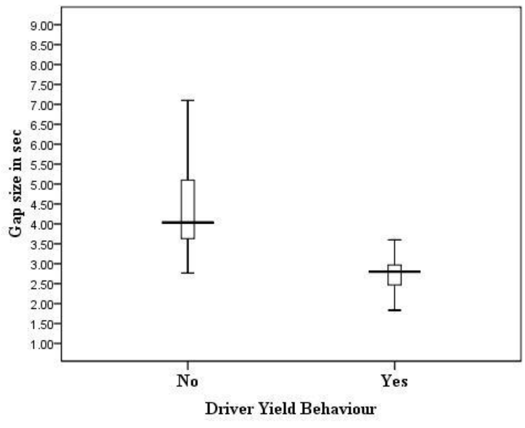

Figure 6. Pedestrian mean accepted gap size based on driver yielding behaviour

Driver yielding behaviour also plays a major role as observed in this study. If pedestrians are already in the middle of the carriageway, the driver yielding behaviour becomes important. While pedestrians are commendably crossing the road, drivers may effectively reduce vehicular speeds or may change their vehicular paths to yield to the pedestrians. Due to this driver yielding behaviour (reducing vehicle speeds or change their vehicular paths), pedestrians are accepting small vehicular gap sizes. Figure 6 shows the pedestrian driver yielding behaviour with vehicular gap size. The mean accepted gap sizes in seconds without driver yielding and with driver yielding are 4.05 and 2.84 respectively. It can be observed that there is a significant reduction in mean accepted gap size when vehicular drivers yield to pedestrians. If vehicular drivers continuously yield to pedestrian, then the vehicular flow characteristic decreases drastically. However, the pedestrian may be benefited with this driver yielding behaviour, but driver may not always yield. Hence, it is a statistically significant variable for the minimum gap size in the MLR model.

In the BL model for pedestrian gap acceptance, only four variables such as gap size, rolling gap, frequency of attempts and vehicular speed were significant and included in the model. Pedestrian road crossing behaviour can be correctly predicted by choice model by consideration of the above variables. Moreover, there is a probability of increasing pedestrian gap acceptance with the increase of the gap size, rolling gap and frequency of attempts, whereas, it reduces with the increase in vehicle speed. The other factors like gender, age, observation duration at curb or median, number of observations at curb or median, observation duration while crossing and baggage are not significant factors to predict pedestrian road crossing behaviour by both minimum gap (MLR) and gap acceptance (BL model) models.

6. Conclusions

In this study the pedestrian behavioural aspects are considered at the microscopic level which includes variables such as observation duration at curb and median, number of observations at curb and median, observation duration while crossing, number of observations while crossing, speed change condition, crossing path change condition, frequency of attempt and rolling gap. These behavioural characteristics are principally dynamic for gap selection and gap acceptance under mixed traffic condition. These behavioural characteristics are very useful to control pedestrian jaywalking behaviour and for improving pedestrian safety. As pedestrian waiting time increases at the curb or median they may lose their patience and this leads to increase in the rolling gap behaviour to cross the road. Rolling gap behaviour is observed more with younger age groups, so the increase in age results in increase in accepted gap size. This study highlights the importance of driver yielding behaviour at uncontrolled mid-block locations. If the driver yielding behaviour increases there is a drastic increase in pedestrian accepting small gap sizes. If pedestrian accepts the lag, it indicates that the accepted lag value is higher than the usual gap size. So, from the model used in this study (MLR and BL model) it can also be concluded that the accepted gap size will increase when the pedestrian accepts lag (first vehicular gap). In accepting lag (first vehicular gap) case the pedestrian shows normal behaviour (no use of rolling gap condition) and they cross the road with higher safety. However, the available lag in mixed traffic condition is very rare so the pedestrian usually apply tactics to reduce their waiting time. In general vehicle type is important factor for accepting the gaps, but this study it is found that pedestrians are accepting vehicular gaps with respect to vehicle speed. It can be justified by the fact that small vehicles may come with higher speeds. So, the pedestrian may not accept the available gaps with small vehicles in mixed traffic condition at higher speeds and sometimes heavy vehicle gaps may be accepted due to less speed. So due to this, speed of the vehicle plays important role in both the models (MLR and BL models). This study also addresses the frequency of the attempt, due to increase in waiting time at the curb or median when pedestrians may frequently attempt available gaps. When they succeed with small vehicular gaps, the probability of gap acceptance also increases. Due to absence of protected walkways (footpaths) at midblock location pedestrians are waiting at paved shoulder. When vehicles are coming with high speed or close to pedestrians, the efforts of searching vehicular gap reduces because of this frequency of disturbance of the vehicle. In this condition pedestrian may look for higher vehicular gap size.

Moreover, based on the field survey it has been observed that the pedestrian jaywalking behaviour is higher at uncontrolled mid-block location due to less regulation of pedestrian activities. Obviously it leads to less safety at an uncontrolled mid-block location as compared to the other locations. Hence, it appears realistic that a decrease in driver yielding behaviour at an uncontrolled mid-block location further reduces safety. Another interesting observation from this study is that the frequency of attempting gap and pedestrian rolling gap behaviour at uncontrolled mid-block locations increased the probability of accidents. However, this pedestrian rolling gap behaviour may increase the probability of pedestrian gap acceptance with small gap size. It is believed that the developed models and study findings may be quite useful to the policy makers to regulate pedestrian jaywalking behaviour at uncontrolled mid-block locations. It is our opinion that the developed models perform quite well in mixed traffic condition in developing countries.

Limitation and future work

This study contributes detailed analysis of pedestrian road crossing behaviour at uncontrolled mid-block location under mixed traffic condition. This study has some limitations. First, pedestrian’s age was considered based on the physical appearance. There is need to consider the exact age of pedestrian, individual age data would improve the present model. Second, due to the field constrains, the length of video coverage section (40m) is limited, due to this the behaviour at protected pedestrians crossing are not predicted. There is a need to evaluate the protected versus unprotected pedestrian road crossing behaviour in mixed traffic condition. Thirdly, speed of the vehicle is also considered within the crosswalk area only due to minimal video coverage. Further, some pedestrians crossing behaviour was overlooked due to visibility complications because heavy vehicles obstructed the position of pedestrians. These unexploited cases may have inflated slightly the pedestrian observation duration at curb or median and number of observations at curb or median. The pedestrian speed change and path change condition obtained in this study cannot be generalised (just considered as binary condition). Pedestrians may walk faster or may reduce their speed in various situations (e.g., in rolling gap condition pedestrian may reduce or increase their speed according to the available gap and there are multiple path change conditions). There is a need to evaluate the pedestrian road crossing behaviour with individual specific speed as well as path change conditions. The findings of the current study were limited to four lane divided road. Hence, the authors are currently working on the study of effect of pedestrian road crossing behaviour for various typical roadway conditions prevailing in Indian cities.

References

Antonini, G., Bierlaire, M., Weber, M. (2006) “Discrete choice models of pedestrian walking behaviour”, *Transportation Research Part B*, 40(8), pp. 667-687.

Brewer, M. A., Fitzpatrick, K., Whitacre, J. A., Lord, D. (2006) “Exploration of pedestrian gap-acceptance behavior at selected locations”, *Transportation Research Record 1982, Journal of the Transportation Research Board,* Washington D.C., pp.132-140.

Cherry, C., Donlon, B., Yan, X., Moore, S. E., Xiong, J. (2010) “Illegal mid-block pedestrian crossings in China: gap acceptance, conflict and crossing path analysis”, *Journal of Injury Control and Safety Promotion*, 19(4), pp. 320-330.

Daamen, W. (2004) “Modelling passenger flows in public transport facilities”, *PhD thesis*, Delft University.

Das, S., Manski, C. F., Manuszak, M. D. (2005) “Walk or wait? an empirical analysis of street crossing decisions”, *Journal of Applied Economics*, 20(4), pp. 529-548.

Dommes, A., Cavallo, V., Vienne, F., Aillerie, I. (2012) “Age-related differences in street-crossing safety before and after training of older pedestrians”, *Accident Analysis & Prevention*, 44(1), pp. 42-47.

Gupta, U., Tiwari, G., Chatterjee, N., Fazio, J. (2009) “Case study of pedestrian risk behaviour and survival analysis”, *Journal of the Eastern Asia Society for Transportation Studies*, 7, pp.1-17.

Himanen, V., Kulmala, R. (1988) “An application of logit models in analysing the behavior of pedestrians and car drivers on pedestrian crossings”, *Accident Analysis & Prevention*, 20(3), pp. 187-197.

Hunt, M., Harper, D. N., Lie, C. (2011) “Mind the gap: Training road users to use speed and distance when making gap-acceptance decisions”, *Accident Analysis & Prevention*, 43(6), pp. 2015-2023.

Iacono, M., Krizek, K., El-Geneidy, A. (2010) “Measuring non-motorized accessibility: issues, alternatives and execution”, *Journal of Transport Geography*, 18, pp. 133-140.

Ibrahim, N. I., Kidwai, F. A., Karim, M. R. (2005) “Motorists and pedestrian interaction at un-signalised pedestrian crossing”, *Proceedings of the Eastern Asia Society for Transportation Studies*, 5, pp. 120-125.

Ishaque, M. M., Noland, R. B. (2008) “Behavioural issues in pedestrian speed choice and street crossing behaviour: A review”, *Transport Reviews: A Transnational Trans-disciplinary*, 28(1), pp. 61-85.

Jiangang, S., Yanyan, C., Futian, R., Jian, R. (2007) “Research on pedestrian behaviors and traffic characteristics at unsignalized midblock crosswalk: a case study in Beijing”, *Transportation Research Record 2038, Journal of Transportation Research Board*, Washington D.C., pp. 23-33.

Kadali, B. R., Vedagiri, P. (2013) “Marked versus unmarked pedestrian road crossing behaviour at uncontrolled midblock crosswalk in mixed traffic condition”, 92nd *TRB Annual Meeting, Transportation Research Board, National Research Council, Washington D.C.*

Khan, F. M., Jawaid, M., Chotani, H., Luby, S. (1999) “Pedestrian environment and behaviour in Karachi, Pakistan”, *Accident Analysis and Prevention*, 31(4), pp. 335–339.

Kim, J. K., Ulfarsson, G. F., Shankarc, V. N. (2008) “Age and pedestrian injury severity in motor-vehicle crashes a heteroskedastic logit analysis”, *Accident Analysis & Prevention*, 40(5), pp. 1695-1702.

Knoblauch, R. L., Pietrucha, M. T., Nitzburg, M. (1996) “Field studies of pedestrian walking speed and start-up time”, *Transportation Research Record 1538, Journal of the Transportation Research Board*, Washington D.C., pp. 27–38.

Kumar, P., Parida, M. (2011) “Vulnerable road users in multimodal transport system for Delhi”, *Journeys*, LTA, 6, pp. 38-47.

Kwon, Y., Morichi, S., Yai, A. (1998) “Analysis of pedestrian behavior and planning guidelines with mixed traffic for narrow urban streets”, *Transportation Research Record 1636, Journal of the Transportation Research Board*, Washington D.C., pp. 116-123.

Lobjois, R., Cavallo, V. (2007) “Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task”, *Accident Analysis & Prevention*, 39(5), pp. 934-943.

Mitman, M. F., Cooper, D., DuBose, B. (2010) “Driver and pedestrian behavior at uncontrolled crosswalks in tahoe basin recreation area of California”, *Transportation Research Record 2198, Journal of the Transportation Research Board*, Washington D.C., pp.23-31.

Mohan, D., Tsimhoni, O., Sivak, M., Flannagan, M. J. (2009) “Road Safety in India: Challenges and Opportunities”, *University of Michigan*, USA.

MOUD (2008). “Study on traffic and transportation policies and strategies in urban areas in India”, *Ministry of Urban Development*.

Oxley, J., Fildes, B., Ihsen, E., Charlton, J., Day, R. (1997) “Differences in traffic judgments between young and old adult pedestrians”, *Accident Analysis & Prevention*, 29(6), pp. 839-847.

Rastogi, R., Chandra, S., Vamsheedhar, J., Das, V. R. (2011) “Parametric study of pedestrian speeds at midblock crossings”, *Journal of Urban Planning and Development*, 137(4), pp. 381-389.

Shahin, M. M. (2006) “Pedestrian behaviour with mixed traffic in developing countries”, *Traffic Engineering and Control*, 47(8) pp. 303-309.

Shay, E., Fan, Y., Rodriguez, D. A., Khattak, A. J. (2006) “Drive or walk ? utilitarian trips within a neotraditional neighbourhood”, *Transportation Research Record 1985, Journal of the Transportation Research Board*, Washington D.C., pp. 154-161.

Sisiopiku, V., Akin, D. (2003) “Pedestrian behaviors at and perceptions towards various pedestrian facilities: an examination based on observation and survey data”, *Transportation Research Part F: Traffic Psychology and Behaviour*, 6(4), pp. 249-274.

Sun, D., Ukkusuri, S. K., Benekohal, R. F., Waller, S. T. (2003) “Modeling of motorist-pedestrian interaction at uncontrolled mid-block crosswalks”, 82nd *TRB Annual Meeting, Transportation Research Board, National Research Council, Washington D.C.*.

Tarawneh, M. S. (2001) “Evaluation of pedestrian speed in Jordan with investigation of some contributing factors”, *Journal of Safety Research*, 32(2), pp. 229-236.

Timmermans, H., Van der, H. X., Borgers, A. (1992) “Transportation systems, retail environments and pedestrian trip chaining behaviour: Modelling issues and applications”, *Transportation Research Part B*, 26(1), pp. 45-59.

Tiwari, G., Bangdiwala, S., Saraswat, A., Gaurav, S. (2007) "Survival analysis: pedestrian risk exposure at signalized intersections", *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(2), pp. 77-89.

Varhelyi, J. (1998) "Drivers' speed behavior at a zebra crossing: a case study", *Accident Analysis & Prevention*, 30(6), pp. 731-743.

Yagil, D. (2000) "Beliefs, motives and situational factors related to pedestrians self-reported behavior at signal-controlled crossings", *Transportation Research Part F: Traffic Psychology and Behaviour*, 3(1), pp. 1-13.

Yannis, G., Papadimitriou, E., Theofilatos, A. (2010) "Pedestrian gap acceptance for mid-block street crossing", *World Transport Research* -Proceedings from the 12th World Conference on Transport Research, pp. 1-11.

Zhuang, X., Wu, C. (2011) "Pedestrians' crossing behaviors and safety at unmarked roadway in China", *Accident Analysis & Prevention*, 43(6), pp. 1927-1936.