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Gap Acceptance of Crossing Pedestrians at Unprotected Mid-Block Crosswalks in Urban Divided Highways

V. Wickramasinghe, D.G.V.C. Diddeniya and K.G.M. Lakmali

Abstract: Unprotected mid-block crosswalk is a hazardous location for the pedestrian. To fulfil the crossing action at a mid-block crosswalk in divided highways, the pedestrian must accept two gaps in the two directional flows. The primary objective of this research is to find out whether there exists any significant difference between these two accepted gaps independent of each other. A video footage was collected at an unprotected mid-block crosswalk located in a two-lane two-way divided dual carriageway. The data was extracted using an image processing software. Hypothesis testing was performed. The paired t-test results showed that there is no significant difference between the mean accepted gap values of the two crossing actions. The secondary objective was to develop a gap estimation model for an unprotected crosswalk in a divided highway. The effective gap was selected as the dependent variable to fit the model. Multiple linear regression model was fitted in order to estimate the gap acceptance with pedestrian characteristics and vehicle stream characteristics. Gender, age, crossing point, waiting time, and crossing speed were selected as pedestrian characteristics while vehicle type and lane number were selected as vehicle stream characteristics. R-studio statistical software was used for the model analysis. The regression model was developed with significant variables, gender, and vehicle type. The results showed that, females are accepting a higher gap (12.3 seconds) than males (9.46 seconds) when using crosswalks in divided highways with two lanes under heterogeneous traffic conditions. Considering vehicle type, the highest average accepted gap was for heavy vehicles while the lowest was for motorbikes. The findings of this study can be useful for traffic planning whilst assuring the safety of both the pedestrian and the driver.

Keywords: Unprotected mid-block crosswalks, Divided highway, Critical gap

1. Introduction

Pedestrians are a significant element of the urban road network system. Crossing pedestrians at un-signalized mid-block crosswalks get more attention due to the hazardous exposure. In Sri Lanka, 18.2% of road accidents have occurred on pedestrian cross walks in 2013 and 77.1% out of that was on mid-block pedestrian crossings. Thus, mid-block pedestrian crossings have contributed to more than 75% of the pedestrian crossing accidents [1]. Crossing pedestrians' safety depends on the characteristics of pedestrians and behavior of drivers. Other than that, most of the South Asian countries have heterogeneous traffic conditions on the road network. Sri Lanka is not an exception. According to past researches, the accepted gap during the heterogeneous traffic flow is higher compared to homogeneous traffic flow [2]. In addition, many researchers have developed models such as regression models, logit models etc., to obtain pedestrians' safety in urban road transportation systems analysing gap acceptance of crossing pedestrians. In two-way, dual carriageway mid-block un-signalized crosswalks, pedestrians have to take two consecutive gaps to finish the crossing action as shown in Figure 1. The primary objective of this research is to find out whether there exists any significant difference between these two accepted gaps.

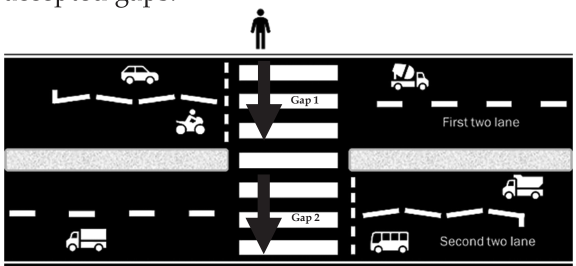

Figure 1 - Unprotected Mid-Block Crosswalk in Two-Lane Two-Way Divided Highway

Eng. (Dr.) V. Wickramasinghe, AMIE(SL) BSc.Eng.(Hons), MEng, PhD, Senior Lecturer, Sri Lanka Institute of Information Technology, Email:vasantha.w@sliit.lk
https://orcid.org/0000-0001-9031-3382
Eng. D.G.V.C. Diddeniya, BSc.Eng.(Hons) in Civil Engineering (Sri Lanka Institute of Information Technology) Email:vishmacharuka@gmail.com
https://orcid.org/0000-0002-2263-2012
Miss. K.G.M. Lakmali, BSc (Special) in Statistics (Colombo), Lecturer in Faculty of Humanities and Sciences, Sri Lanka Institute of Information Technology.
https://orcid.org/0000-0002-2707-9156

2. Literature Review

Chaudhari et al. [3] and Kadali et al. [4] were concerned about the gap acceptance of pedestrians with relevance to pedestrian behavioural characteristics and type of vehicles approaching the crosswalk. Only a few studies have considered the gap acceptance of pedestrians at unprotected mid-block crosswalks and even fewer studies have considered the divided highways where pedestrians should take two consecutive gaps to finish the crossing action. Yannis et al. [5] from Greece researched on the critical gap. The field survey was opted for, allowing actual crossing behaviour to be observed. Moreover, a log-normal regression model was developed in order to examine the effect of various parameters on pedestrian gap acceptance, defined as the size of traffic gaps accepted by pedestrians. A binary logistic model was also developed, so that the effect of traffic gaps and other parameters on the pedestrians' crossing decision has been examined.

Jain et al. [6] developed a pedestrian gap acceptance model at mid-block crosswalk. In the study, researchers have investigated behavioural characteristics relevant to pedestrians like crossing speed, rolling behaviour, etc. Six different mid-block locations in Bhopal and Indore were considered for the study. As a data collection method, these researchers have used video surveys. In data extraction, 13,281 gaps were recorded. As per the observation of the authors, elderly pedestrians and female pedestrians waited longer as compared to younger pedestrians and male pedestrians. Same variation has been observed by Khan et al.[7] and Tiwari et al.[8]. To formulate the gap acceptance model, researchers used multiple linear regression technique and hypothesis testing. Generally, the study focused on the effects of demographic and behavioural characteristics of pedestrians on accepted pedestrian gap sizes.

Type of vehicles approaching the pedestrian on crosswalk also affects the pedestrian's gap acceptance decision. Pedestrian's crossing speed and waiting time also vary with the type of approaching vehicle. When a vehicle approaches towards a male pedestrian, the average speed is shown as 1.21 m/s and that of a female pedestrian as 0.92 m/s. Typically, female pedestrians have obtained 12.38% lower speed than male pedestrians when crossing the road. Khan et al. [7] mention that deviation of gap accepting percentage of female pedestrians was higher than the male pedestrians. Accepted gap of male pedestrians did not achieve any higher variation with regard to the type of vehicle [3]. In this study, data collection method was similar to most of the other researches. A video survey was used for data collection and AVS software was used as the video to image converter for data extracting method. This software has an accuracy of 33 milliseconds in each video frame. To analyse the data, MINITAB17 software was used. It should be noted that this research has not considered the difference of accepting gap of pedestrians in each of the two parts (i.e., two directional flow) of dual carriageway separately.

Typically, most of the studies consider the factors impacting on gap acceptance of the pedestrians. Zhao et al. [9] stated six environmental characteristics impact on pedestrians' gap accepting decision at unprotected mid-block crosswalks in divided highways under homogeneous traffic congestion: gap size, crossing distance, number of waiting pedestrians, waiting time, vehicle traffic volume and position of pedestrian (whether on street kerb or median). However, the study did not consider the difference of acceptance gap of the pedestrians in the first half of the dual carriageway and second half of the dual carriageway separately. If the pedestrian stops his/her movement on the median, the current research has considered movement of the second part of the carriageway as a new data set. According to the study by Zhao et al. [9], gap size and crossing distance make a significant impact on the decision of pedestrians' accepted gap.

For the data extraction, most of the researchers have used video to image converting software. Most of them have used AVS and Wondershare-Filmora software for data extraction.

Considering the data analysis method, previous researchers used statistics for the analysis. Majority of the researchers have selected either Multiple Linear Regression (MLR) or Artificial Neural Network (ANN) to formulate gap acceptance models with different explanatory variables [4]. Critical gap cannot be obtained from the field survey. There are several methods to evaluate the pedestrian's critical gap such as HCM method, Raff's method, MLE, Logit method. HCM method is based on the pedestrian's decision-making time and pedestrian's speed to cross the road [10]. Raff's method is based on probability distribution of rejected gap and accepted gap data [11]. MLE method is based on the accepted gap data and maximum rejected gap data [12].

By considering previous literature, authors decided to adopt a video survillence to obtain data and image processing technique to extract data. Hypotheis testing and MLR were considered for the data analysis.

3. Methodology

Methodology of this study consists of four sections, Site selection, Data collection, Data extraction and Data analysis as discussed below.

3.1 Site Selection

A crosswalk in Battaramulla suburb in Colombo, Sri Lanka with a four-lane unprotected mid-block dual carriageway section of 100 m in length between unsignalized crosswalks, was selected for the survey. Vehicle density is moderate and pedestrian density is high at the selected location.

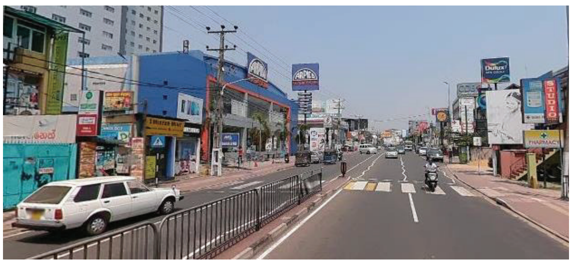

Figure 2a - Selected Crosswalk for the Study (6.90N, 79.91E)

Figure 2b - Camera Mounting at the Survey Location

3.2 Data Collection

Data collection was done by video graphic survey. Video recording was done at the peak time of a weekday. In the morning, a three-hour recording was done from 7 am to 10 am to cover the office time and school time. In the evening, a two-hour recording was done from 4pm to 6pm to cover the office closure time. Figure 2 shows the arrangement of cameras at the location.

3.3 Data Extraction

Collected video was converted to a 33millisecond video frame using AVS software and data was extracted manually. Figure 3 shows the interface of the AVS software used for data extraction. Pedestrian behavioral characteristics and vehicle platoon characteristics were collected from the video. Gender, attire, age group, waiting time at curb, rejected gaps and accepted gaps to all four segments of the road with seconds, oncoming vehicle type to each lane, waiting time at median, crossing times of each and every carriageway and total crossing time were extracted from the video. The overall extracted data sample comprised 350 data points for each identified variable. Among them, 202 were men and 148 were women.

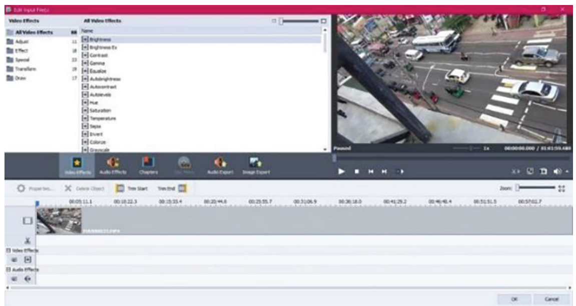

Figure 3 - Video to Image Processing

3.4 Data Analysis

The main objective of this study was to identify the difference between gap acceptance of the pedestrians in the first half of the dual carriageway (street-curb to median) with the gap acceptance of the pedestrians in the second half of the dual carriageway (median to other side street-curb). Hypothesis test was performed as follows:

H_0 - *μ accepted gap in first half - μ accepted gap in second half = 0*

There is no significant difference in gap acceptance of pedestrians between the first half of the dual carriageway and second half of the dual carriageway, because of the experience in first half.

H_1 - *μ accepted gap in first half - μ accepted gap in second half $\neq$ 0*

There is a significant difference in gap acceptance of pedestrians between the first half of the dual carriageway and second half of the dual carriageway.

Secondary objective of this study was to develop a gap estimation model for an unprotected crosswalk in a divided highway. Thus, multiple linear regression models were fitted in order to estimate the gap acceptance with pedestrian characteristics and vehicle stream characteristics. Gender, age, crossing point, waiting time, and crossing speed were selected as pedestrian characteristics while vehicle type and lane number were selected as vehicle stream characteristics. Using the data extracted from the video, a stepwise regression was formulated to establish the model. Critical gap acceptance value from all four accepted-gaps were selected as the dependent variable while pedestrian behavioural characteristics and oncoming vehicle types were selected as independent variables. Table 1 shows description of the explanatory variables used for the study.

Table 1 - Factors for Model Development

Variable	Unit
Critical gap size	seconds
Waiting time	seconds
Crossing time	seconds
Starting point	0 – Curb 1 - Median
Attire	0 – T shirt & Trouser 1 – Shirt & Trouser 3 – Saree 4 – Skirt & Blouse 5 – Shirt & Sarong
Lane	0 – Near lane 1 – Far lane
Gender	0 - Female 1 - Male
Age	0 – Young (age<30years) 1 – Elder (age>30years)
Vehicle type	0 – MB 1 – TWL 2 – CVJ 3 – HV

Description of Variables:
Critical gap: Minimum time gap between oncoming vehicle and crossing pedestrian with reference to the reference line on crosswalk (sec)
Waiting time: Time lost at the curb or median for getting accepted gap (sec)
Crossing time: Time taken by pedestrian to cross the carriageway (sec)
Starting point: Pedestrian's position when he/she starts to cross the lane (If on curb – 0 or on median – 1)
Attire: Pedestrian's costume
Lane: Whether the lane is near or far to the starting point of pedestrian
Gender: Male or Female
Age: Young considered as below 30years and Elder considered as above 30years
Vehicle type: MB – Motor Bike, TWL – Three-wheel, CVJ – Car, Van, Jeep, HV – Heavy vehicle

Multiple Linear Regression (MLR) method was used to fit the model using R STUDIO software. MLR method is the most common form of linear regression analysis. Normal form of linear regression analysis is,

$Gap = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots.. + \beta_n X_n$

where,
Gap: Minimum time gap between oncoming vehicle and crossing pedestrian with reference to reference line on crosswalk (sec).

4. Results and Discussion

4.1 Hypothesis Test

Hypothesis test was performed using the observed data of pedestrians. The paired t-test was done using the SPSS software in order to check whether there is any significant difference between two accepted gaps which are taken while crossing the two segments of the mid-block crosswalks in a divided highway. The results obtained from the t–test is shown in Table 2.

Table 2 - Paired Sample Test Results

	t	Sig. (2-tailed)
Pair 1 Critical gap 1 Critical gap 2	-0.299	0.766

It was observed that the 2-tailed t-test gives a significant value of 0.766, implying that the significant value of the t-test is in the rejected range which is more than 0.05. Hence it rejected the H_1 (Alternative Hypothesis) and accepted the H_0 (Null Hypothesis). The paired t-test results show that there is no significant difference in gap acceptance of pedestrians between the first half of the dual carriageway and second half of the dual carriageway, because of the experience in first half.

4.2 Gap Estimation Model for Crossing Pedestrians

The minimum accepted vehicular gap by pedestrians was modelled considering the pedestrian characteristics and the vehicle stream characteristics. A stepwise Multiple Linear Regression analysis (MLR) was performed using RSTUDIO software. Extracted data was run under stepwise method by omitting the insignificant variables to get the most accurately fitted model. Results of the final fitted model are shown in Table 3.

Table 3 - Coefficients and p-value of Significance Variables

	Coefficient	t-value	p value
(Intercept)	3.6872	7.892	4.09e-12
MB	-0.9142	-1.717	0.0891
TWL	-1.3178	-2.414	0.0176
CVJ	-0.3095	-0.633	0.5280
Gender Female	0.9198	3.335	0.0012

The results show that vehicle type MB (motor bike) is fairly significant because its p-value is very close to 0.05 and TWL (three-wheeler) is very significant because its p-value is 0.0176 (<0.05). But vehicle type CVJ (car, van, jeep) is not significant. According to the statistics principles, if any individual variable becomes significant among categorical variables, full set of categorical variables are considered as significant. Hence vehicle type was considered as a significant variable. The level of gender significance was very high.

4.3 Developed Model

From the results obtained, the gap estimation model is as follows:

$$Gap = 3.6872 - 0.9142 \times MB - 1.3178 \times TWL - 0.3095 \times CVJ + 0.9198 \times Female \quad \dots (1)$$

Assumptions were satisfied according to the graphs obtained from model validation process. Durbin-Watson test and Anderson-Darling test were done to check the linearity and normality. To satisfy the linearity check, Durbin-Watson value should be between 1.5 – 2.5. In the current research the value is observed to be 2.238 and p-value from the Durbin-Watson test should be higher than 0.05 which is confirmed by the observed value of 0.8958. Normality of the model is checked by Anderson-Darling test and p-value should be higher than 0.05 as same as the Durbin-Watson test. In the current research, p-value of the Anderson-Darling test is found to be 0.577. So, there are no violations of the linearity and the normality of the model.

5. Conclusions

This study mainly focused on finding out whether there exist any significant difference between the two accepted gaps where the pedestrians might get when crossing unprotected mid-block crosswalk in a divided dual carriageway. Considering the results obtained from t-test, it is concluded that there is no significant difference in gap acceptance of pedestrians between the first half of the dual carriageway and the second half of the dual carriageway, because of the experience in the first half.

The secondary objective of this study was to develop a model to predict the critical gap of pedestrians when crossing unprotected mid-block crosswalks in divided highways using MLR (Multiple Linear Regression) technique. According to the model results, oncoming vehicle type and gender of the pedestrian are the most influential factors on gap acceptance of pedestrians. Among the vehicle types, three-wheeler is the most influential category for the gap acceptance. The results showed that females are getting more time than males when crossing the crosswalks. Attire is the most insignificant variable and it showed that attire does not create any influence on gap acceptance decision.

The developed model is validated for pedestrian crossings at divided carriageways with critical gaps. Thus, the model is limited to above conditions.

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