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Pedestrian Crossing Behavior at Three Urban Signalized Intersections in Colombo

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Abstract: The pedestrians crossing behavior at signalized intersections has become one of the main factors contributing intersections related crashes. Understanding the pedestrian crossing behavior is important as the behavior of these vulnerable group are random and inconsistent, which in turn led to make the objective of this study. Waiting endurance times of pedestrians in three urban intersections were studied during both peak and off-peak hours. Data on pedestrian characteristics were extracted from recorded videos and coded the eight different characteristics of pedestrians. The behavioral differences among gender and age groups were examined including the identification of the different crossing patterns. The results showed that most of the male pedestrians and old pedestrians tend to produce violent crossing characteristics. It was also noted that many pedestrians neglect to adhere to a straight path during crossing.

Keywords: Pedestrian Crossing; Signalized Intersections; Waiting endurance times

1. INTRODUCTION

World Health Organization (WHO) reported 491,530 pedestrian fatalities in road traffic crashes in 2014 in the world (WHO, 2015). Among them 29% were car occupants while 27% were pedestrians and 20% were motorized two-wheelers or three-wheelers. In 2014, one in every six children under the age of 14 who were killed in traffic crashes were pedestrians crossing at signalized intersections (WHO, 2015). There is a clear geographic distribution of pedestrian mortality, with the proportion of pedestrians killed in relation to other road users being highest in the African Region (41%) and lowest in the South-East Asia Region (17%).

In recent years motor vehicle ownership in Sri Lanka has been dramatically increased resulting more vehicles at the road. To ensure that the maximum number of vehicles cross at the intersections, road designers allocated more time for vehicles. However, time extending for vehicles results more waiting time for pedestrians to cross the street. This makes the pedestrians to cross during the red man phase which became one of main contributing factors for increasing the number of pedestrian- related crashes at signalized intersections.

A pedestrian crossing or a crosswalk is the place designated for pedestrians to cross the road. Pedestrian crossings are the supplementary collaborators for the pedestrians to cross the road safely. These crossings are usually marked by white or yellow stripes on the roadway and are also known as zebra crossings. Traffic signals for pedestrians are often located on busy intersections to stop vehicles and allow large numbers of people on foot to cross safely. Crosswalks are designed to keep pedestrians together where they can be seen by motorists,

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and where they can cross most safely across the flow of vehicular traffic. The time that the pedestrian is waiting at the crosswalk to start crossing the road is called the Waiting Endurance time. Identifying an optimum waiting endurance time will help more urban residents to choose walking as the mode of transportation for short trips avoiding traffic congestion. The objectives of this study were to investigate different behavioral characteristics of crossing pedestrians by their gender and age groups and determine the mean waiting endurance time of pedestrians crossing at the selected signalized intersections in Sri Lanka.

2. LITERATURE REVIEW

Many scholars have done work on pedestrian crossing characteristics and waiting endurance time. The study in China showed that motor vehicle ownership in Beijing has undergone rapid vehicle growth and also the planning and design of signalized intersections have given priority to the efficiency of vehicle movement (Zhang et al., 2016). As endurance time is the time that the pedestrian should wait at the crossing to cross the road and when the pedestrians tend to lose patience due to high endurance time, accidents at pedestrian crossings are very common. For the analysis of the problem the authors obtained data via manual roadside observations and video analysis. The waiting endurance time of pedestrians crossing at signalized intersections in Beijing was found to be 52.58 seconds. Gender and age were identified as two main influence factors for endurance time of pedestrians. Also, five categories of influence factors were determined. They are road factors, environmental factors, pedestrian characteristics, trip time, and traffic conditions.

The crossing behaviors of 239 pedestrians were investigated at two signalized intersections in Kuala Lumpur, Malaysia by Hamidun et al. (2016). Pedestrian behavioural data were observed on different days which covered the noon and evening peak periods where the pedestrian behaviors were captured using a video camera. The behavior of pedestrians was documented according to ten crossing activities and the differences between males and females were noted. From the analysis the researchers were able to determine that one of the main factors contributing to the high risk of crashes as crossing behavior. The disregard of the call button function at signalized intersections caused serious problems whereas the crossing path seemed to make certain violence. Three types of crossing styles were observed in this study: straight, crossing and crossing between stopped vehicles. The differences among gender only emerge in the two coded behaviours related to spatial violation while started crossing while the traffic light for vehicle turn green. It was found that men significantly often started their crossing randomly and tend to execute dangerous crossing at signalized intersections. This might become the reason why men always have higher involvement in pedestrian accidents.

Brosseau et al. (2013) determined the impact of pedestrian waiting time at an intersection on the proportion and type of pedestrian violations and dangerous crossings. Thirteen intersections which had similar geometry and traffic conditions but different maximum waiting times were observed. Data were collected manually at least two hours in each intersection for the main analysis and complementary videos were recorded for validation. The age, gender, group size, pedestrian flow, and pedestrian signals had been identified as having an impact on the proportion of pedestrian violations. In addition, this study identified that maximum waiting time (red phase) and an intersection clearing time had an impact on violations and on the proportion of dangerous crossings committed. The pedestrians' crosswalk speeds depended on the type of crossing. It was concluded that highlighting the importance of minimizing waiting times for pedestrians which was expected to reduce dangerous pedestrian behaviors at signalized intersections.

Cinnamon et al. (2011) investigated the potential relationship between violations made by pedestrians and motorists at signalized intersections, and collisions between pedestrians and motor-vehicles in Vancouver, Canada. In this study, geographic information systems was used to identify the high-incident pedestrian injury intersections and then violations of road rules by pedestrians and motorists at high incident pedestrian injury locations were observed. About 9,000 pedestrians and 18,000 vehicles were observed among them about 2000 pedestrians and 1000 drivers committed one of the observed violations. The method provides the basis for understanding the relationship between violations and pedestrian injury risk at intersections. It was concluded that the results can be applied for targeted prevention campaigns designed to reduce the pedestrian injury risk.

Pedestrian crossing behaviour at seven urban intersections was observed in Delhi, India by Tiwari et al. (2009). Data collection was done by placing a video camera at each zebra crossing and then data were extracted by reviewing of the videotapes. Pedestrian crossing behaviour was analysed using survival analysis statistical methodology. Kaplan–Meier survival curves were produced for waiting time prior to crossing unsafely, separately for males and females for each intersection. It was found that mean waiting time of females were 27% more than that of males. The waiting time of 90% of female pedestrians were 44% more than that of males. The probability for a pedestrian to cross the road, when it was unsafe, varies with waiting time. As waiting time increases, pedestrians get impatient and violate the traffic signal. Therefore, reduction of waiting time for pedestrians are likely to decrease the probability of pedestrian crossers being hit by a motor vehicle.

3. DATA AND METHODOLOGY

To study the pedestrian crossing behavior at urban signalized intersections, the data on the pedestrian behavioural characteristics and waiting endurance time of the pedestrian crossings at the selected intersections were collected. This target was achieved with the help of manual data collection surveys and CCTV video data. Three urban signalized intersections were selected; Kohuwala, Alexandria Place, and Thimbirigasyaya which are located in Colombo, Sri Lanka. The data collection was done for three selected crossings at both peak and off peak times to maintain the balance. Traffic conditions and the respective road environment of the signalized intersections are shown in Table 1.

Table 1. Traffic and road characteristics of the observed intersections

Characteristics	Signalized Intersection		
	Kohuwala	Thimbirigasyaya	Alexandria Place
Survey Section	Colombo – Horana Road	Havelock Road	C.W.W Kannangara Mawatha
Crosswalk Length (m)	10.13	11.20	21.65
Number of Lanes	4	4	7
Green time of pedestrians (sec)	50	50	85
Red time of pedestrians (sec)	60	60	90
Yellow time of pedestrians (sec)	0	0	0
Land Property Use	Public	Public	Public

Crossing activities executed by pedestrians were divided into two phases considering the activities before and during crossing and were documented according to seven different crossing activities as shown in Table 2.

Table 2. Observed pedestrian crossing characteristics

Acceptable Characteristics	Violent Characteristics
Before Crossing	
• Non - use of mobile phones • Looking at traffic before crossing • Standing on the pavement to cross • Started crossing within the marked crosswalk	• Use of mobile phones • Not looking at traffic before crossing • Standing on the road to cross • Started crossing outside the marked crosswalk
During Crossing	
• Non - use of mobile phones • Looking at traffic during crossing • Crossing within the marked crosswalk • Starting to cross on the green man phase • Type of Crossing(Straight, Diagonal, Between stopped vehicles)	• Use of mobile phones • Not looking at traffic during crossing • Crossing outside the marked crosswalk • Not starting to cross on the green man phase • Type of Crossing(Straight, Diagonal, Between stopped vehicles)

The influence factors for waiting endurance were identified through analyzing the locations of the pedestrian crossings at the three selected intersections and relating them to existing studies. As shown in the Table 3 the influence factors were classified into four categories: environmental factors, pedestrian characteristics, trip time, and road environment. It was expected that endurance time depends on these factors.

Table 3. The identified influence factors

Classification	Factors
Environmental factors	Temperature
Pedestrian Characteristics	Age, Gender
Trip Time	Trip Time
Road Environment	Crosswalk Length, Land property use

3.1 Sample Size Calculations

Sample size determination is the act of choosing the number of observations or replicates to include in a statistical sample. The sample size is an important feature of any empirical study in which the goal is to make inferences about a population from a sample (Walpole, 2016). Three equations were used for the calculation of sample size. (Walpole, 2016).

$$x = Z(\frac{c}{100})^2 r(100 - r) \tag{1}$$

where:

x : response distribution,
r : fraction of responses that you are interested in,
Z(c/100) : critical value for the confidence level c, and
C : confidence level.

$$n = Nx/((N-1)E^2 + x) \tag{2}$$

where:
n : sample size,
N : population size, and
E : margin of error.

$$E = Sqrt[\frac{(N-n)x}{n(N-1)}] \tag{3}$$

The population of Colombo district in 2016 was 752, 993. Assuming marginal error of 5%, confidence level of 95%, Response Distribution of 50%, the obtained minimum sample size was 384 pedestrians.

3.2 Data Collection

CCTV videos were obtained for the three selected intersections from the CCTV Camera division of Sri Lanka Police. Video data were used to determine pedestrian behavioral characteristics and onsite data collection methods were used to obtain waiting endurance time data. Endurance time data were taken with the consideration of influence factors such as environmental factors, pedestrian characteristics and traffic conditions. Both crossing characteristics and endurance time were recorded manually on the data collection sheets. Each site was visited, allocating one week for each intersection and covering all the days and the peak and off peak times to obtain pedestrian behavioral characteristics. A total of three weeks were taken for the data collection survey, covering all the selected signalized intersections. Data were collected from 7:30am to 5:30pm covering both peak and off peak hours for the crossing characteristics as well as waiting endurance time. Obtained data were used to identify different behavioral characteristics by the gender and age where the acquired data were classified into two phases considering the activities of pedestrians before and during crossing.

3.3 Analysis

The chi-squared test was used to determine whether there was a significant differences between the expected frequencies and the observed frequencies in one or more categories or to test the independence of two categorical variables. Null hypothesis in chi-squared test is two categorical variables are independent. The Alternative hypothesis is two categorical variables are dependent. The confidence level chosen was 95% with significance level of 5% where the boundary to check the dependency becomes 0.5. This value is called the p – value.

Mean waiting endurance time of pedestrians crossing at all three selected intersections were determined, including the 25th and 75th percentiles. Then, a Cox's Proportional Hazards Regression Model was developed for the signalized intersection with the highest mean waiting endurance time so that the endurance time and the identified influence can be compared qualitatively. Cox regression (or proportional hazards regression) is a tool for investigating the effect of several variables upon the time a specified event takes to happen.

Provided that the assumptions of the cox regression are met, this function would provide better estimates of survival probabilities and cumulative hazard than those provided by the Kaplan – Meier function. The coefficients in a cox regression relate to hazard; a positive coefficient indicates a risk factor and a negative coefficient indicates a protective factor. The Cox's proportional hazards regression model is as follows:

$$h(t,X) = h(t)\exp\left(\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p\right) = h_0(t)\exp(\beta_x) \quad (4)$$

where:

t	: Waiting endurance time of crossing pedestrians (s),
X_1, X_2	: Influence Factors,
ß1' ß2	: Regression coefficients for influence factors,
h(t,X)	: risk function at time t, and
$h_0(t)$	: Risk function at time t when influence variable is 0.

3. RESULTS AND DISCUSSION

In this study, about 2,310 pedestrians were observed during both phases and analyzed covering all three intersections, including 615 (55%) males, 540 (45%) females, and 676 (57.58%) young, 479 (42.41%) old pedestrians as shown in Table 4.

Table 4. Number of pedestrians observed

Intersections	Number of Pedestrians				
	Male	Female	Young	Old	Total
Kohuwala	201	184	249	136	770
Thimbirigasyaya	195	190	217	168	770
Alexandria Place	219	166	210	175	770
Total	615	540	676	479	2,310

The violent characteristics which are detailed in Table 2, were observed. Table 5 shows the number of pedestrians who produced violent characteristics at all intersections with regard to age and gender.

Table 5. Number of pedestrians producing violent characteristics

Intersections	Number of Pedestrians							
	Before Crossing				During Crossing			
	Male	Female	Young	Old	Male	Female	Young	Old
Kohuwala	102	67	97	72	86	71	95	62
Thimbirigasyaya	74	41	62	54	70	42	61	51
Alexandria Place	41	25	28	28	59	30	61	28

According to the results it was derived that 39.53% of pedestrians tend to cross between stopped vehicles at the Alexandria Place intersection while 48.51% of pedestrians tend to cross in a straight pathway at the Kohuwala intersection. About 36.23% pedestrians cross diagonally at the Alexandria Place intersection. It was observed that the Thimbirigasyaya intersection had the lowest number of pedestrians using false crossing types. That includes 19.56% of pedestrians crossing between stopped vehicles and 29.76% of pedestrians crossing diagonally. Only 26.95% of pedestrians crossed in a straight path, which is considered as the correct type of crossing, in this intersection. The results represent the behavior of pedestrians who arrived at the crosswalk on the red man phase as well as the green man phase, thus pedestrians arriving at the red man phase executed three main behaviors: they approached, executed and crossed. Pedestrians arriving at the green man phase were able to cross the road straight away. Pedestrians from both these types were included in the results.

Waiting endurance times of the pedestrians were also recorded. A certain number of pedestrians arrived at the crosswalk area during the green man phase where a waiting endurance time of 0s. Those samples were discarded in analyzing the waiting endurance time. Therefore, the collected number of waiting endurance time was 1,155. Table 3 shows the mean waiting endurance time samples and the respective percentiles obtained for the studied signalized intersections. According to the results for mean Waiting Endurance time at all three intersections, the Kohuwala intersection produced the highest value as 71.644s.

Table 6. Waiting endurance times of studied intersections

Intersections	Mean waiting endurance time(s)	25^{th} Percentile waiting endurance time(s)	75^{th} Percentile waiting endurance time(s)
Kohuwala	71.644	52	95.4
Thimbirigasyaya	58.089	37.5	80.98
Alexandria Place	42.583	37.25	46.12

The difference between behavior of males and females and age groups were tested using X^2 tests in Kohuwala intersection. There were not significance differences between male and females on mobile phone use or looking at traffic before crossing while waiting for green-man phase. Male pedestrians were more likely wait for green-man phase on the carriageway to cross compared to females ($P<0.05$). Males were more likely to start crossing outside the marked crosswalk than females ($P<0.05$). The males more likely to use mobile phone while travelling on crosswalk than that of females ($p=0.02$). There were no significant differences between males and females on watching traffic while crossing. Male pedestrians were more likely to cross outside the marked crosswalk compared to females. Also, females were more likely to start crossing on green-man phase compared that of females.

Young pedestrians more likely to use mobile phone while crossing on crosswalk than that of older pedestrians ($p=0.04$). Old pedestrians more likely to looking at traffic before crossing compared to young pedestrians ($p=0.04$). A significant differences between the age groups were not observed on waiting on carriageway or start the crossing outside the cross walk. Young pedestrians were more likely to use mobile phone while crossing on crosswalk than that of older pedestrians ($p=0.02$). There were no significant differences between young and old pedestrians on watching traffic while crossing. Young pedestrians were more likely to cross outside the marked crosswalk compared to older pedestrians. There were not significance differences were observed between age groups on starting the walk of green-man phase.

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The Cox's Proportional Hazards Regression Model was prepared for the waiting endurance time samples at the Kohuwala Intersection. This was to determine the quantitative relationship between the waiting endurance time and the identified influence factors when the type of distribution obeyed by the waiting endurance time is known. Only the pedestrians who crossed during the red man phase has a risk possessed, therefore only that particular number of pedestrians were used in preparing the model which was approximately 281 pedestrians.

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Alexandria Place	42.583	37.25	46.12

The Cox's proportional hazards regression model of the waiting endurance time of pedestrians crossing at the Kohuwala Intersection were as follows:

$$h(t) = h_0(t) \exp(-0.623 \times X_{T27} - 0.214 \times X_{T28} - 0.679 \times X_{T29} + 0.219 \times X_{T30} - 0.512 \times X_G + 0.319 \times X_{A1} - 0.781 \times X_{A2} + 0.121 \times X_{T1} + 0.237 \times X_{T2} + 0.964 \times X_{T3} + 0.0314 \times X_c - 0.134 \times X_L) \quad \textbf{(5)}$$

$$PI = -0.623 \times XT27 - 0.214 \times XT28 - 0.679 \times XT29 + 0.219 \times X\ T30 - 0.512 \times X\ G + 0.319 \times XA1 - 0.781 \times XA2 + 0.121 \times XT1 + 0.237 \times XT2 + 0.964 \times XT3 + 0.0314 \times Xc - 0.134 \times XL \quad \textbf{(6)}$$

Table 7. Coefficient Estimated Cox's Proportional Hazards Regression Model for Kohuwala Intersection

Variable	Variable Definition	Variable Code	Regression Coefficient
Temperature	Temperature is 27℃=1	X_{T26}	-
	Temperature is 27℃=2	X_{T27}	- 0.623
	Temperature is 28℃=3	X_{T28}	- 0.214
	Temperature is 29℃=4	X_{T29}	– 0.679
	Temperature is 30℃=5	X_{T30}	- 0.219
Gender	Male=1, Female=0	X_G	– 0.512
Age	Young=1, otherwise=0	X_{A1}	+ 0.319
	Old=1, otherwise=0	X_{A2}	– 0.781
`Time of the day	Morning=1, otherwise=0	X_{T1}	+ 0.121
	Afternoon=1, otherwise=0	X_{T2}	+ 0.237
	Evening=1, otherwise=0	X_{T3}	+ 0.964
Crosswalk length(m)	Continuous variable	Xc	+ 0.0314

The interpretation of results as follows.

Temperature: There were five observed data collection temperatures. With the temperature 26℃ as the reference, the regression coefficient of X_{T27} was – 0.623; this value was less than zero, so it was considered as a protective factor. The relative risk rate $e^{-0.623}$ was 0.536. The regression coefficient of X_{T28} was – 0.214; this value was also less than zero proving that it was a protective factor. The relative risk rate $e^{-0.214}$ was 0.807; this rate showed that the waiting endurance time of pedestrians crossing when the temperature was 27℃ was higher than when the temperature was 28℃. The regression coefficient of X_{T29} was – 0.679, which was also less than zero proving that it is a protective factor. The relative risk rate $e^{-0.679}$ was 0.507; this rate showed that the waiting endurance time of pedestrians crossing when the temperature was 27℃ was less than when the temperature was 29℃. The regression coefficient of X_{T30} was –0.219; this value was also less than zero, where it was also considered to be a protective factor. The relative risk rate $e^{-0.219}$ was 0.803; this rate showed that the waiting endurance time of pedestrians crossing when the temperature was 27℃ was higher than when the temperature was 30℃.

Gender: The regression coefficient of X_G was – 0.512; this value was also less than zero, where being male was also considered to be a protective factor. The relative risk rate $e^{-0.512}$ was 0.600.

Age Groups: The regression coefficient of X_{A1} (young) was + 0.319; this value was greater than zero, where it was considered to be a risk factor. The relative risk rate $e^{+0.319}$ was 1.375. The regression coefficient of X_{A2} (old) was - 0.781; this value was also less than zero, where it was also considered to be a protective factor. The relative risk rate $e^{-0.781}$ was 0.457.

Trip Time: Trip time was divided into three categories: morning, afternoon and evening periods. With the morning period as the reference object, the regression coefficient of X_{T1} was + 0.121; this value was greater than zero, where it was considered to be a risk factor. The relative risk rate $e^{+0.121}$ was 1.129. The regression coefficient of X_{T1} was + 0.237; this value was greater than zero, where it was considered to be a risk factor. The relative risk rate $e^{+0.237}$ was 1.267; this rate showed that the endurance time on the morning period was more than the afternoon period. The regression coefficient of X_{T1} was + 0.964; this value was greater than zero, where it was considered to be a risk factor. The relative risk rate $e^{+0.964}$ was 2.622; this rate showed that the endurance time on the morning period was more than the evening period.

Crosswalk Length: The regression coefficient of X_C was + 0.0314; this value was greater than zero, where increasing the crosswalk length was considered to be a risk factor. The relative risk rate $e^{+0.0314}$ was 1.032.

The Cox's Proportional Hazard Regression Model generated for the Kohuwala Intersection proved that the endurance time depends on the influence factors.

5. CONCLUSIONS AND RECOMMONDATIONS

A total of 2310 pedestrians were observed which included 1,320 males (57.14%) and 990 females (42.85%). It was observed that most reckless behavioral patterns are produced in signalized pedestrian crossings. Pedestrians tend to break pedestrian crossing rules repeatedly where a larger percentage of male and young pedestrians are leading the reckless pedestrian lists. There were significant differences between the results obtained for males and females as well as old and young age groups where the significance was confirmed through the statistical analysis techniques, the Chi – Squared test was very useful in differentiating between different types of crossing respective to gender and age groups at all three intersections.

The mean waiting endurance time samples obtained for the three intersections were, 71.661s for the Kohuwala Intersection, 58.089s for the Thimbirigasyaya Intersection and 42.583s for the Alexandria Place Intersection. From the results and observations of this study it can be concluded that both crossing characteristics and waiting endurance tie depends on gender, age and the surrounding road and traffic conditions, which would deny the safety of pedestrians and increase conflicts with vehicles at signalized intersections.

The results obtained from this research can be optimized by extending this study further. This would be done by determining more variables that can affect pedestrian crossing characteristics and influence factors that can affect waiting endurance time. The results obtained from this study can be used as a baseline for further research. The increment of the aggressiveness of the behavior of crossing pedestrians was the only constraint observed during the study. Therefore, it is recommended to carry out a survey to determine and investigate the ideas of crossing pedestrians so that the respective precautions can be adhered. People tend to cross the road at intersections between stopped vehicles and vehicle users block the way of the pedestrians by stopping the car on the pedestrian crossing. The professional bodies whom responsible should take care to tighten rules and regulations regarding these matters to uplift the safety of pedestrians as well as reduce traffic congestion.

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