Sigma Journal of Engineering and Natural Sciences, Vol. 42, No. 6, pp. XX-XX, December, 2024
Yildiz Technical University Press, Istanbul, Turkey

Study on pedestrian crossing decision at the roundabouts

Neeraj S. N[1], Vijay B.G.[2*], Abdullah AL-MANSOUR[3]

ABSTRACT

The pedestrians are the most exposed amongest all road traffic users to the possibility of being attacked or harmed, either physically or emotionally. In the present investigational study, an attempt is made to develop the model on pedestrian road crossing behaviour by considering the elements of pedestrian crossing behaviour, especially the size of the vehicular gap accepted by pedestrians and also pedestrians decision to cross or not cross the road. A field investigation was carried out at two zebra crossing facilities located at two major roundabouts in Shivamogga city. Data collection and extraction was done by utilising video-graphic data in real-time traffic conditions by the Department of Traffic Police, Shivamogga and also, by observing the behaviour of pedestrians while crossing the road. The study will also aid in determining correlations between pedestrian characteristics, crossing facilities, and vehicular traffic. This data will be analysed by regression methods in statistical analysis. As a result of this research, it is intended that a model of pedestrian gap acceptance and pedestrian crossing choice could be developed that also includes the factors that pedestrians look for when accepting the vehicle gaps between the vehicles to cross the crosswalks in roundabouts.

Keywords: *Pedestrian Crosswalks; Pedestrian Platoon; Jaywalk*

INTRODUCTION

People who walk on foot or who use a walking stick or other forms of assistive devices are referred to as pedestrians. Walking is one of the most common ways for people to get around. Every mode of transportation makes use of some walking. The present study is carried out in Shivamogga city with a latitude and longitude of 13° 55' 47.7480'' N and 75° 34' 5.1600'' E and it is one of the most prominent and fast developing cities in India, having a population of 387,000 as per (2022 census). There are three types of reasons for this expansion. Residential arcades, educational hubs, and industrial complexes are all examples of shopping and commercial activity and their centres. The radial or axial roads and transit routes that connect the perimeter to the centre, which continue to be the key connection to the activity, are the principal hindrance to this structural growth. Shivamogga's density profile follows a conventional urban pattern, with the highest density in the centre sector and decreasing density in the outward areas.

Figure 1. Shivamogga Location.

This paper was recommended for publication in revised form by Regional Editor Ahmet Selim Dalkilic
[1] Department of Civil Engineering Jawaharlal Nehru National College of Engineering affiliated to Visvesvaraya Technological University, Belagavi, Karnataka, India.
[2] Faculty in Department of Urban Transport Infrastructure Management, Ethiopian Civil Service University, Addis Ababa, Ethiopia.
[3] Civil Engineering Department College of Engineering King Saud University Riyadh, Saudi Arabia
** E-mail address: vijaybg@ecsu.edu.et*
Orcid id: https://orcid.org/0009-0002-9349-0901 Neeraj S. N., 0000-0003-1427-5403 Vijay B. G., 0000-001-9881-7032 Abdullah Al-Mansour
Manuscript Received 11 April 2023, Revised 22 May 2023, Accepted 27 July 2023

The last few decades has witnessed rapid growth of Shivamogga city due to the increase in population beacouse of the following reasons: Migrants from rural areas seeking employment, the attractiveness of good weather conditions (salubrious climate), the presence of Education institutions for learning and research, the existence of commercial centres, shopping malls etc. due to these, a growth in the number of pedestrians which is also a cause for an increase in the number of traffic accidents mainly in major rotary intersections where vehicles and pedestrians share the same space and both pedestrian and traffic movements are continuous. This scenario will lead to clash between the vehicles and pedestrians while crossing the road. Sometimes this conflict will lead to accidents which would even result in pedestrians fatalities.

LITERATURE REVIEW

BL (binary logit) model and a discrete probability model was also developed to better understand vehicular gap acceptance by pedestrians. By considering vehicular, road geometrics and pedestrians related variables, the MLR model was developed to determine the size of the pedestrians gap acceptance at the main crosswalks in Kuala Lumpur [1, 2, 3]. [4, 5] It was also noticed that age of the pedestrian and the phase of the departure signal had a significant impact on differences in crossing speeds. Also both gender and group size had an impact on pedestrian compliance behaviour. Several investigational studies are being carried out all over the world to better understand pedestrian behaviour, which is influenced by a variety of elements such as pedestrian factors roadway factors and traffic conditions, recently in Mumbai an investigational research was carried out [6] to assess how people behave at signalised intersections with mixed traffic. Using logistic regression models, the likelihood of pedestrian violations and interactions was calculated and confirmed. Using the statistical tests, the factors influencing pedestrian compliance with traffic signals were identified. [7] In Malaysia it was found that each pedestrian had a unique perception of the safest gap to cross when accepting gaps. Their physical attributes have an impact on their movement, such as walking speed. Taller pedestrians accept smaller gaps than shorter pedestrians because they can typically walk more quickly than them. [8,9] Carried out a study on the gap acceptance behaviour of pedestrians in relation to pedestrian age after discovering that one of the major reasons for pedestrian accidents was age-related decline in gap selection ability. They divided pedestrians into three groups based on age. They've carried out experiments on the vehicle time gap and the vehicle speeds were systematically changed. The pedestrians walking and pedestrians decision were examined using an ANOVA, and the results were examined using post hoc Tukey tests. It was found that older pedestrians made unsafe crossing judgments because they left wider distance gaps and not longer time gaps like, their younger counterparts. [10] conducted a study on how pedestrians used major crosswalks in Washington, D.C., USA, and found that they did not always wait until all lanes were completely clear before crossing; instead, they believed that lanes would clear as they crossed and used a rolling gap. [11] Developed a lognormal regression model to assess the acceptance of pedestrian gaps in an uncontrolled mid-block location in Greece. Using a binary logistic regression model, it was determined whether waiting time, speed, distance, and traffic gaps affected pedestrians' decisions about whether or not to cross the street. It was also discovered that the distance from the approaching vehicle as opposed to its speed had a significant impact on the decision to cross. [12] Developed a realistic model to comprehend the interaction between pedestrians and vehicles. The analysis revealed a p-value that is less than 0.05. [13, 14, 15] several models were developed to predict the relationship between variables, binary logistic regression is a statistical method.it was found that the normal distribution is similar to BL regression. [16, 17] conducted a study in Mumbai city in India at six signalised intersections to study the variables influencing pedestrian crossing behaviour and crosswalk safety. A probability model was developed using a binary logit model to study the variables influencing pedestrian crossing behaviour. The developed models were validated, and the results revealed that the models had accurately predicted how pedestrians would behave at signalised intersections and their level of safety. It was discovered that the significant influencing factors, such as the ideal green time, the length of crosswalks, education, employment, and Refugee Island, had an impact on pedestrian noncompliance behaviour.

DATA COLLECTION

The information on pedestrian crossing behaviour was gathered by a video graphic method and field survey. The study locations were selected based on the region with the highest volume of vehicles and pedestrians. Within the vicinity of major shopping complexes, employment centre and Public transportation centres of Shivamogga city are the two locations, "Amir Ahmed Circle" and "Ashoka pillar circle," as shown in Figure-2 and Figure-3. The intersections geometrical data, vehicular data and pedestrian data were collected and extracted from the video-graphic data collected by the Department of Traffic Police, Shivamogga. A total 29,679 pedestrians were clearly observed from video graphic recording to find detailed information about pedestrian crossing behaviour. Pedestrians who crossed the road either in the crosswalk or outside the crosswalk have been considered in the present study.

Figure 2. Study location-1 "AA Circle".

Figure 3. Study location-2 "Ashoka pillar".

Figure 4. Study location stretch -1"AA Circle".

Figure 5. Study location stretch-2“Ashoka pillar Circle”.

DATA EXTRACTION AND ANALYSIS

Several elements should be identified before beginning the analysis such as pedestrian crossing time, waiting time, pedestrian crossing speed vehicle volume vehicle speed and vehicle [18, 19, and 20]. Data analysis is the steps which involves developing a model to analyse data. All the information gathered by the video graphic data with an accuracy of 1 in 15 secs using Share X software, as shown in Figure-4 and Figure-5, has been checked for correctness and usefulness. This is critical to ensure that the process does not impede the development of the model.

Figure 6. Extraction of Data from recorded Video graphic recordings “AA Circle”.

Figure 7. Extraction of Data from Video- graphic recordings "Ashoka pillar Circle".

All the information gathered has been checked for correctness and usefulness. Continuous variables and discrete variables are two factors which are considered while determining the kind of variables that should be included in the study data from video camera recordings. Figure-6 & Figure-7 shows the extraction of data from the collected video graphic recordings. The acquired behavioural data gives a clear and detailed interaction between pedestrians and vehicular traffic in the crosswalks of signalised intersections. Table: 1 and Table: 2 provide a summary of the details of the variables information gathered from the video graphic data and geometrics of the study locations.

Table 1. Variables considered for the study.

Variable	**Unit or Code**
Pedestrian speed	m/sec
Pedestrian Volume	pedestrian/hour
Gender	0: Women 1: Man
Pedestrian age	0: Children, 1: younger, 2: older
Pedestrian Volume	pedestrian/hour
Gap acceptance	0: Rejected, 1: Accepted
Pedestrian platoon	0: Single, 1: Two & more than two
Traffic volume	vehicle/hour
Vehicle speed	m/s
Vehicle Type	0: Two wheelers,1: Three-wheeler, 2: four-wheeler,3: LCV, 4: bus & truck 5: other
Waiting Time	Time in sec
Pedestrian Gap size	Time in sec
Presence of median	0: No 1: Yes

Table 2. Geometrical variables considered for the study.

Study location stretch -1 "AA Circle"	
Intersection Number of Lane	4 Lane
Length of crosswalk (m)	17
Width of crosswalk (m)	3.55

Study location stretch -2 “Ashoka pillar”	
Intersection Number of Lane	6 Lane
Length of crosswalk (m)	16
Width of crosswalk (m)	3.75

MODEL DEVELOPMENT

The multiple linear regression technique was used to model the significance of variables on pedestrian road crossing behaviour at roundabouts. The pedestrian behavioural parameters in the model were used to calculate the vehicular gap size that is typically accepted by pedestrians in roundabouts. After numerous iterations on various independent variables, the final model with the best statistical results is generated using the SPSS software. By considering all the variables treated as independent variables, while the gap acceptability treated as a dependent variable. The pedestrian gaps more strongly matched with the lognormal distribution, which suggested that the log gap resembles the normal distribution. [21, 22, 23]. The model is calibrated with 80% of the data and the remaining 20% of the data is utilised to validate the model by using MAPE technique. The calibrated R^2 value is found to be 0.812 in the present case. The descriptive statistics of the MLR test, T-test and P-values with 95% confidence interval were compiled, as shown in Table 3. The comparison of observed (remaining 20% data) and anticipated values demonstrated the correctness of the calibrated model as a viable model.

$$\textbf{Log Gap (Size)} = 24.68 + 0.495(PCS) - 0.410(PWT) - 1.23(G) - 1.26(A) - 6.125(J) + 0.426(VS) + 0.156(VT) - 0.327(WR) \ldots\ldots\ldots \quad (1)$$

Where Log-Gap = Logarithm of accepted gap, PCS = crossing Speed, PWT = Pedestrian Waiting Time, G = Gender, A=Age, J = Jaywalk, VS = Vehicle Speed, VT = Vehicle Type, WR = Width of road.

Table 3. MLR model.

Variables	Co-efficients	t-value	p-value
Const*	24.688	17.526	0.000
Pedestrian Gender	-1.230	-2.016	0.042
Pedestrian Age	-1.260	-3.425	0.023
Pedestrian Waiting Time	-0.410	-4.213	0.010
Pedestrian crossing Speed	0.495	1.509	0.21
Jaywalk	-6.125	-5.623	0.000
Vehicle Speed	0.426	-12.586	0.00
Vehicle Type	0.156	4.235	0.001
Width of road	-0.327	-2.37	0.000

Table 4. ANOVA (Analysis of Variance).

Model	Df	Sum of square (SS)	Mean of square (MS)	F	Significance, F
Regression	1	91324.41286	91324.41286	74.12571147	0.004158012
Residual	12	6318.748161	1232.020726		
Total	13	97643.16102			

(Df: degrees of freedom)

From the analysis of variance shown in Table: 4 the significance level 0.004158012 <0.05 which means variables considered in the present study are affecting the minimum gap size accepted by the pedestrians significantly, It also shows it is a stronger regression model.

The choice of behaviour (Crossing/not crossing) was investigated using a binary logit model (BL Model) constructed with SPSS software by considering data at both study locations. Table 5 summarises the descriptive statistics of the BL Model test. Based on the below table, the p-value is used to identify the variables that fit the model statistically. Every other factor must have a significant value of less than 0.1 (p-value 0.1) to be appropriate for a decision model. According to the analysis, the vehicle gap size accepted by pedestians and vehicle speed that have significance value of less than 0.1, are the influencing factors for the model.
with a significance value of less than 0.1, the vehicle gap size accepted by pedestrians and vehicle speed are significant factors for the model

Table 5. Summaries of B.L Model.

Variables	B-Coefft	Std E	Sig.	Exp(B)
Const*	6.32	0.453	0.000	12.362
Type of vehicle	0.27	0.12	0.375	1.521
Vehicle speed	-0.29	0.42	0.002	0.956
Road Width	0.004	0.003	0.228	1.001
Walking Speed	-0.35	0.42	0.198	0.812
Waiting Time	0.020	0.25	0.463	4.052
Gap Size	-0.14	0.004	0.021	3.895
Jaywalk	-0.65	0.125	0.461	2.100
Pedestrian platoon	0.25	0.15	0.526	4.745

X=6.32-0.29(VS)-0.14(GS)……………………..(2)

Where VS =Vehicle speed, GS=Gap size.

Due to a significant value greater than 0.1, the remaining components are irrelevant. Equation (2) shows how the model is fitted to the data using the maximum likelihood method. Binary logit regression shown in Equation (3) will describe the probability of a pedestrian crossing the crosswalks in roundabouts depending on vehicular gap size and speed of the vehicles.

$$\mathbf{P(C)} = \frac{e^x}{1+e^x} \quad \text{……………..} \ (3)$$

RESULTS AND DISCUSSION

It is observed that the mean pedestrian gap sizes at roundabouts for men and women are 3.91 and 4.58. A majority of previous research has a different gap size for controlled and un controlled crosswalks [24, 25, 26] present study is carried out in roundabouts where the same format of risk taking behaviours were observed like the pedestrian crossing in un controlled crosswalks its also observed that the mean pedestrian gap size at roundabout for children, younger and older age groups were 3.504, 3.35 and 4.95 respectively. Table: 6 gives the detailed gap acceptance classification among different age groups and gender.

Table 6. Gap accepted size by pedestrians.

Gender/Demographic	Gap size (Sec)		
	Minimum	Maximum	Mean
Male	2.75	5.59	3.91
Female	3.89	7.00	4.58
Children’s	2.99	6.32	3.50
Younger	2.10	7.35	3.35

Older age	3.25	10.50	4.95

The other factors such as width of the roads, medians and curbs are not significant predictors of pedestrian road crossing behaviour in both the models.

CONCLUSIONS

In the present study, pedestrian crossing decisions and gap accepted by the pedestrians were clearly observed at two significant roundabouts of Shivamogga city. The following conclusions are drawn based on the findings

1) The influence of various variables on the size of vehicular gaps allowed by pedestrians in roundabouts is investigated using a lognormal regression model. The acceptable gaps were found to be dependent on the following factors such as pedestrian walking speed, pedestrian waiting time, pedestrian gender, pedestrian age, jaywalk, vehicle speed, vehicle type, and road width.

2) In order to investigate the factors in roundabouts that affect a pedestrian's decision to cross the road or not, a BL regression model was also developed. The findings revealed that pedestrian crossing decisions were primarily influenced by the size of the gap and the speed of the vehicle.

3)The average gap size accepted by the men and women are 3.91 and 4.58 and average accepted gap sizes in seconds for children, younger and older age groups are 3.504, 3.35, and 4.95 respectively.

4) The equations obtained are validated using mean absolute percentage error (MAPE) method. An average error of 8.2 and 7.9 percent is found between observed and estimated values; this reinforces the analysis.

5) When the vehicle speed is lower, the likelihood of crossing the road by pedestrians is higher, whereas when the gap size is less, the likelihood of crossing the road by pedestrians is lower.

6) The developed models and findings will be very useful to the policy makers in regulating pedestrian ambler walking behaviour at the roundabout locations for improving pedestrian safety.

Funding
This work was supported by Researchers Supporting Project Number (RSP2023R424), King Saud University, Riyadh, Saudi Arabia.

Acknowledgments

The authors would like to acknowledge the support provided by Researchers Supporting Project Number (RSP2023R424), King Saud University, Riyadh, Saudi Arabia.

REFERENCES

[1] A. Dommes, V. Cavallo, J.B. Dubuisson, I. Tournier and F. Vienne, Crossing a twoway street: Comparison of young and old pedestrians, *J. of Safety Research, 50, 27– 34 (2014).*

[2] Kadali B. R. and Vedagiri P., (2013), Modelling pedestrian road crossing behavior under mixed traffic condition*, European transport, 3 (55), ISSN 1825-3997.*

[3] Siti Naquiyah M, N and Basil David Daniel., et al., (2017) “Analysis of Pedestrian Gap Acceptance and Crossing Decision in Kuala Lumpur” *MATEC Web of Conferences 103, 08014.*

[4] A. Jain, A. Gupta and R. Rastogi, Pedestrian crossing behaviour analysis at intersections, *Int. J. of Traffic and Transportation Engineering, 4, 103–116 (2014).*

[5] 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.*

[6] Marisamynathan and Perumal,V., (2014) “Study on pedestrian crossing behavior at signalized intersections”. *Journal of Traffic and Transportation Engineering, vol. 1(2), pp. 103-110.*

[7] B.H. Goh, K. Subramaniam, Y.T. Wai and A.A. Mohamed, Pedestrian crossing speed: the case of

malaysia, *Int. J. of Traffic and Transport Engineering, 2, 323–332 (2012).*

[8] Cherry C., Donlon B., Yan X., Moore S. E., and 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.*

[9] J.A. Oxley, E. Ihsen, B.N. Fildes, J.L. Charlton and R.H. Day, Crossing roads safely: An experimental study of age differences in gap selection by pedestrians, *Accident Analysis and Prevention, 37, 962–971(2005).*

[10] Brewer AM, Fitzpatrick K, Whitacre AJ, and Lord D (2006). "Exploration of pedestrian gap-acceptance behavior at selected locations". *J Transp Res Rec 1982:132–140 17.*

[11] J.M. King, D.W. Soole and A. Ghafourian, Illegal pedestrian crossing at signalized intersections: Incidence and relative risk, *Accident Analysis and Prevention, 41, 485– 490 (2009).*

[12] D. Sun, S.V. Ukkusuri and R.F. Benekohal, (2002) "Modeling of motorist-pedestrian interaction at uncontrolled mid-block crosswalks." *Transportation Research Record, Urbana, 51, 61801.*

[13] Jiangang S., Yanyan C., Futian R., and 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.*

[14] M. Brewer, K. Fitzpatrick, J. Whitacre and D. Lord, Exploration of pedestrian gap acceptance behavior at selected locations. *J. of the Transportation Research Board, 1982, 132–140 (2006).*

[15] Oxley J., Fildes B., Ihsen E., Charlton J., and Day R., (1997), Differences in traffic judgments between young and old adult pedestrians, *Accident Analysis & Prevention, 29(6), pp 839-847. 21.*

[16] Marisamynathan S, Vedagiri P (2018) "Modelling pedestrian delay at signalized intersection crosswalks under mixed traffic condition." *Proc-Soc Behav Sci 104:708–717.*

[17] Marisamynathan, S., and P. Vedagiri. Modeling (2017) "Pedestrian Level of Service at Signalized Intersection Under Mixed Traffic Conditions." *Transportation Research Record: Journal of the Transportation Research Board, 2634: 1–18.*

[18] T. Wang, J. Wu, P. Zheng and M. McDonald, Study of pedestrians' gap acceptance behavior when they jaywalk outside crossing facilities, *13th Int. IEEE Conference, 1295–1300 (2010).*

[19] Yannis G., Papadimitriou E., and 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.*

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

[21] G. Yannis, E. Papadimitriou and A. Theofilatos, Pedestrian gap acceptance for midblock street crossing. *Transportation Planning and Technology, 36, 450–462 (2013).*

[22] 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.

[23] Marisamynathan, S., and P. Vedagiri. (2016) "A New Approach to Estimate Pedestrian Delay at Signalized Intersections." *Transport, 33(1), pp. 249–259.*

[24] Oxley J., Fildes B., Ihsen E., Charlton J., and Days R., (2005), crossing roads safely: An experimental study of age differences in gap selection by pedestrians, *Accident analysis and prevention 37, pp 962-971.*

[25] 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.*

[26] Shahin M. M., (2006), Pedestrian behavior with mixed traffic in developing countries, *Traffic engineering and control, 47(8) pp 303-309.*