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Pedestrian Road Crossing Behavior and Optimal Selection of Pedestrian Facilities at Mid-Block Crossings

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Abstract

Pedestrians are considered the most vulnerable of all road users, particularly in developing counties. Therefore, the safety of pedestrians plays a significant role during road crossing. The pedestrian gap acceptance and level of service (LOS) can be used to evaluate pedestrian crossing behavior. The existing statistical models are failed to predict the accurate level of pedestrian safety due to various assumptions. Thus, the objectives of this study are to develop pedestrian crossing behavior models, level of service model, and systematic methodology to select optimal pedestrian crossing facilities at midblock under mixed traffic conditions. The required data were collected from selected six midblock locations in Tiruchirappalli, India, by conducting videographic and questionnaire surveys simultaneously. Various influencing parameters on pedestrian crossing behavior were identified by conducting statistical correlation analysis. First, the pedestrian field critical gap was estimated and compared with various methods such as Raff, Greenshield, Ashworth, and Highway Capacity Manual 2010. The pedestrian gap acceptance model was developed by adopting stepwise multiple linear regression and non-linear artificial neural network methods. The developed models were validated and compared using the field data. The pedestrian LOS model was developed by utilizing the conventional regression method by using qualitative and quantitative data. Pedestrian LOS model was validated using another set of field data. Finally, the approximate solution to find the best crossing facility was found by performing weighting by a ranking method and analytical hierarchy process in all six locations. This study helps in identifying the most significant factors influencing road crossing behavior of pedestrians for the selected locations. The study results help design pedestrian facility and thereby improve pedestrian safety at uncontrolled intersections.

Keywords: Pedestrian, Midblock, Artificial Neural Network, Multiple Linear Regression, Level of Service, Analytical Hierarchy Process

1. Introduction

In a developing country like India, there has been rapid urbanization which resulted in an increase in traffic growth. It led to the rise in urban sprawl, which resulted in an increase in the usage of public transport. In general, walk trips are followed in origin or destination or both of public transportation trip or mode transit points. Even though with an increase in walk trips, traffic research and major developments have always been on vehicles. Pedestrian safety, comfort and convenience have often been secondary while designing roadways. Pedestrian road crossing behavior considers as very complex which results in difficulties while designing facilities for them. In addition, the heterogeneity in

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traffic on Indian roads lead to severe conflicts between pedestrians and motorists and result in a decline in pedestrian safety. Many of these conflicts occur at mid-block crossings and unsignalised intersections. Studies have shown that nearly 1.2million fatalities and 50million injuries were reported in every year due to road crashes globally (Kadali et al., 2015). In addition, 65% of total road crashes were reported which were related to pedestrian alone in India. Particularly, 70% of pedestrian crashes were accounted at midblock crossings. As per recent Indian statistics, 60% of fatalities were pedestrians and 80% of deaths of pedestrians happened at midblock crossings (MoRTH, 2019). The statistics suggest that there has been a spike in pedestrian death by 10.7% in the last year. The statistics mentioned above indicate that pedestrian accident rates are higher at uncontrolled midblock crossing compared with intersections.

Due to the high installation cost and unsatisfactory of the warrant for the signal installation, most of the midblock pedestrian are not signalized in developing countries as well as some developed countries. In general, stop or yield signs are used to control the midblock, where the priority is specified to the pedestrians. But, the pedestrians are receiving more delays to find safer gaps for crossing the high-speed corridors. This kind of situation leads to a high risk for pedestrians due to their failed judgment on gap acceptance. The condition in India is worse than other countries because the road user's noncompliance with traffic rules and drivers yield behavior are not followed strictly. Due to the above-mentioned reasons, pedestrians need to face more waiting times, particularly high vehicular traffic conditions. Therefore, pedestrians are started to accept the lesser gaps and allowing themselves to high risk. To enhance the pedestrian safety, there is a need to conduct research on pedestrian gap acceptance behavior at midblock crossings. The development of the pedestrian level of service (PLOS) model can deliver a clear understating to implement the suitable facilities for pedestrians. Therefore, the objectives of this study are to develop a pedestrian crossing behavior model and systematic methodology to select optimal pedestrian facilities at midblock based on pedestrian characteristics and behavior under mixed traffic conditions.

2. Literature Review

Many existing studies were concentrated on safety issues related to motorized vehicular, and very limited studies were focused on safety issues on pedestrian movement. Most of the studies were identified the significant factors which affected pedestrian crossing behavior by considering socioeconomic, geometric, and traffic characteristics (Tiwari et al., 2007). A study was examined the variant on pedestrian behavior and speed with respect to traffic characteristics at uncontrolled midblock crosswalks in Beijing (Shi et al., 2007). Few studies were explored the pedestrian road crossing behavior by considering before and after scenarios of re-construction of traffic controlling facilities (Gupta et al., 2010). Few studies were examined the effectiveness of educational training programs on pedestrian crossing behavior (Dommes et al., 2012). The average crossing speed was higher in males and children (Jain et al., 2014). The average crossing speed of pedestrians was found to be 1.31 m/s and the 15th percentile crossing speed as 1.07m/s (Onelcin & Alver, 2017). While crossing a typical two-lane undivided road in an urban area, pedestrians were searching the more near gaps instead of far gaps, whereas pedestrian required to find a suitable gap in each lane while crossing the number of vehicular lanes (Kadali & Vedagiri, 2013a).

The relation between pedestrian gap acceptance and time to arrival estimates showed that the typical effect of speed and age with time gap size (Petzoldt, 2014). Raff, Ashworth, lag, harder, Greenshields, acceptance curve and clearing behaviour approaches were used for estimating critical gap at unsignalized intersection for homogeneous and heterogeneous traffic conditions (Highway Capacity Manual, 2010; Kadali & Vedagiri, 2016). The maximum likelihood method was found to give the closest and consistent estimate for critical gap which was not dependent on the traffic volume (Mohan et al., 2015). Rolling gap affected the pedestrian crossing behavior in most when compared to other pedestrian characteristics (Fitzpatrick et al., 2007). A simple logistic regression method was adopted to find the relation between vehicle gaps and other variables related to pedestrian crossing choice (Yannis et al., 2013). Vehicular speed was indirectly related to the distance which was completed by the vehicle (Kadali & Vedagiri, 2013a). The pedestrian accepted gap size decreases due to pedestrian behaviors such as rolling behavior and occurs at roadway with a lower number of lanes under mixed traffic conditions (Kadali & Vedagiri, 2013b). At pedestrian midblock crossing, spatial and temporal gaps or lags were modelled using binary logit technique (Pawar & Patil, 2015). In the transportation field, many studies were adopted to artificial neural network (ANN) technique and limited studies were compared to the ANN with linear regression models in transportation research (Kadali et al., 2015). Multiple linear regression (MLR) and ANN methods were adopted to evaluate the factors which significantly affected the pedestrian gap acceptance behavior at midblock crossing under mixed traffic conditions (Kadali et al., 2015). Various other mathematical models were also developed to explore the pedestrian gap acceptance behavior at different locations (Mohamad Nor et al., 2017).

Very limited studies were conducted on pedestrian LOS at midblock (Kadali & Vedagiri, 2015, 2016). Most of the models were adopted linear regression techniques to predict the LOS score. Very recently, researchers were started to develop the LOS model by combining pedestrian perceptions and field values (Marisamynathan & Vedagiri, 2017). A few studies were conducted to identify the optimal solution for encouraging pedestrians (Sayyadi & Awasthi, 2013). The hierarchical regression method was adopted using questionnaire data which included three specific dangerous pedestrian crossing behavior in developing countries (Sisiopiku & Akin, 2003). A multicriteria decision analysis approach was developed based on the analytic hierarchy process (AHP) for location planning of pedestrian zones under a lack of quantitative data (Sayyadi & Awasthi, 2013).

Most of the existing studies considered age based on physical appearance which fails to give the exact condition of the pedestrian. Different methods of critical gap estimation gave different values with a wide deviation as they were highly dependent on traffic volume. Existing studies have discussed various influencing parameters on pedestrian gap acceptance and gap acceptance modes were developed by adopting linear, probit, binary-logit and non-linear method. Non-linear methods proved to have better prediction capability as they simulate the actual relationship between input and output variables. Furthermore, suitable methods to evaluate pedestrian LOS at midblock is missing for Indian conditions with a combination of quantitative and qualitative data. Finally, none of the studies have developed a methodology to find the optimal selection of pedestrian facilities at midblock by considering heterogeneous traffic conditions. Therefore, it is essential to perform research on pedestrian crossing behavior, LOS, and safety level at midblock in India, adopting an alternative method of including a questionnaire survey to collect actual pedestrian observations on a crossing.

3. Research Objectives

The specific study objectives are as follows: (a) to identify various influencing discrete and continuous parameters affecting pedestrian crossing behaviour at midblock; (b) to evaluate pedestrian safety level by estimating the critical gap of pedestrians and compare with existing standards; (c) to develop a systematic framework to model pedestrian crossing behaviour under mixed traffic conditions; (d) to develop the pedestrian level of service model to estimate actual perceptions of pedestrians; and (d) to develop a model for identifying optimal crossing facilities for pedestrians at midblock based on qualitative data

4. Methodology

A reconnaissance survey followed by a preliminary and primary survey was carried out to fix the study locations. The required data were obtained from selected six midblock. In the first stage, various influencing variables on pedestrian crossing behavior were identified based on statistical analysis. In the second stage, pedestrian critical gap was estimated and compared using various methods. On the third stage, pedestrian crossing behavior models were developed to estimate the pedestrian gap acceptance by adopting and comparing linear (MLR) and nonlinear (ANN) techniques. In the fourth stage, LOS model was proposed by adopting a stepwise regression method. Pedestrian quantitative data extracted from the video and qualitative data from the questionnaire survey were utilized to develop the pedestrian LOS model. In the final stage, AHP was adopted to find the optimal facilities to improve pedestrian safety at crosswalks. Finally, applications of the developed models were drafted in conclusions

5. Data Collection

5.1.Study Locations

Data were collected from Tiruchirappalli (Trichy), Tamil Nadu, India. In Trichy, National Highway – 67 (NH67) is one of the major expressways which consists of high pedestrians and heavy vehicle movement. In this study, a stretch of 15km of NH67 was considered which connects between Palpannai and Thuvakudi. Over this stretch, a total of 12 mid-blocks were identified for conducting the preliminary analysis. In the preliminary survey, the pedestrian volumes were counted in order to select the sites for conducting the primary survey. The comparison of the pedestrian volume was performed at 12 mid-block locations for the years 2013, 2016 and 2018. From the comparisons, six mid-block crossings were finalized to conduct the primary survey. A site investigation was carried out prior to the primary survey to measure the quantitative variables. The variables like median width, carriageway width, number of lanes, presence or absence of zebra crossing, and reference points were measured from the field using a distance measuring tape. The details are presented in Table 1.

Table 1: Geometric characteristics of selected six mid-blocks

Sl. No	Name of Crossing	Crosswalk length (m)	Median Width	Presence of crosswalk marking	Land use pattern
1.	Thiruverembur stop	16	1.5	Yes	Commercial
2.	Balaji Nagar	16	1.5	Half	Residential
3.	Kailash Nagar	16	1.5	Yes	Commercial
4.	Kattur	16	1.5	No	Institutional
5.	St. Little Flowers	16	1.5	Yes	Institutional
6.	Kamraj Nagar	16	1.5	No	Mixed

5.2.Primary Survey

5.2.1. Video-graphic survey

The required data were collected by conducting videographic survey at the selected locations during peak hours. Peak hours were determined by carrying out a traffic count at an interval of 15 minutes from morning 8am to 10am and evening 4pm to 6pm. From volume count, 9 to 10am and 4.30 to 5.30pm were considered as morning and evening peak hours respectively. The selected study locations are presented in Figure 1.

Figure 1: Selected mid-block crossing at Thiruverembur and Balaji Nagar

5.2.2. User perception survey

Pedestrian perceptions of crossing facilities were studied using a questionnaire survey which was performed along with the video-graphic survey during peak hours. The finalized questionnaire form is presented in Figure 2.

Sample Number:			Surveyor Name:
1.	Gender	Male	Female
2.	Age Groups	Less than 12 19-25 36-55	12-18 26-35 More than 55
3.	Platoon Size		
4.	Trip Purpose	Work Recreational Social Others	Shopping Education
5.	Education Level	Primary School (1-5) Senior School (11-12) Postgraduate	Middle School (6-10) Undergraduate
6.	Occupation	Student Private employee Business Others	Laborer/daily worker Government employee Retiree
7.	Frequency of using crosswalk	Regularly (Daily) Always	Rarely
8.	Use of Frequency of mobile phone while crossing crosswalk	Always Sometimes Never	Often Rarely
9.	Extent of Feeling Safe at particular crosswalk	1 – Very Good 3 – Average 5 – Very Bad	2 – Good 4 – Bad
10.	Level of Service with respect to comfort, convenient, safety	1 – Excellent 3 – Good 5 – Bad	2 – Very Good 4 – Average 6 – Very Bad
11.	If you want to provide the facilities, rate the following facilities	Existing Conditions – Foot over bridge – Traffic Signal –	Underpass – Push Button –
12.	How you have rated the above facility?	Safety; Convenient	Comfort; Accessibility

Figure 2: Questionnaire Form

Four enumerators were selected based on their expertise in the local language which is Tamil along with English. The survey was conducted on a total sample of 384pedestrians. Pedestrians were surveyed once they completed the crossing process. The main advantage of this approach was that the pedestrian perception based on their crossing experience in realistic site conditions was collected after immediate crossing. The pedestrians were explained the meaning of the questions and then they were requested to fill the survey sheet.

5.3.Data details

Based on literature reviews, the various parameters were finalized to study pedestrian crossing behavior at mid-block crossings under mixed traffic conditions. The list of considered pedestrian and traffic characteristics were presented in Table 2.

Table 2: Definition of variables with code or unit

Sl. No	Variables	Definition with code or unit
1	Gender (D)	By visual appearance (Male=0; Female=1)
2	Age (D)	By questionnaire survey (18-30=0; 30-55=1; >55=2)
3	Group size (D)	Number of pedestrians in a group. single=0; one=1; two=2 and so on
4	Frequency of attempt (C)	Attempts made by pedestrian to accept a vehicular gap
5	Rolling gap (D)	Behavior of pedestrian rolls over available small gaps. No=0; Yes=1
6	Speed change (D)	Changes on pedestrian crossing speed observered or not. No=0; Yes=1
7	Path change (D)	Crossing pattern adopted. Perpendicular=0; L=1; Oblique=2;
8	Conflicting vehicle speed (C)	Speed of the vehicle approaching the conflicting zone in m/s
9	Vehicle type (D)	Two-wheeler=0; Car=1; Light Commercial Vehicle=2; Heavy Commercial Vehicle=3; Auto=4; Bus=5
10	Accepted gap (C)	Time difference between the last passing vehicle before the pedestrian crossed and next arriving vehicle (in seconds)
11	Rejected gap (C)	Time difference between the two last passing vehicles before the pedestrian crossed (in seconds)
12	Waiting time (C)	Pedestrian waiting time which spent at curb or median (in seconds)
14	Crossing time (C)	Time required for completing the crossing manoeuvre excluding all the waiting time and delay (in seconds)
15	Crossing speed (C)	Pedestrian crossing speed on crosswalk. Taken as crossing distance divided by the crossing time. (m/s)

Note: (D)- discrete, (C)- continuous

6. Data Extraction and Analysis

Recorded videos were played and necessary data were extracted manually using AVS video editor software. The mentioned variables in Table 2 were extracted for all possible observed pedestrians from the collected video. Based on data, various descriptive statistical analyses were performed and results were discussed in this section. The data after cleaning included 4840 gaps for 384 pedestrians. The descriptive statistics of pedestrian characteristics are presented in Tables 3 and 4.

7. Pedestrian Critical Gap Estimation

The pedestrian critical gap is the minimum gap size of the traffic stream which permits the access of a pedestrian to cross the road (Indian Highway Capacity Manual (Indo-HCM), 2018). The critical gap is found by building a cumulative frequency graph of accepted and rejected gaps. The intersecting point of these two cumulative graphs is considered as the critical gap according to Raffs method. This method of critical gap assessment is followed in Indo-HCM, 2018. It was assumed that pedestrians cross the crosswalk if the accepted headway is more than critical headway. It was found that measurement of critical headway for an individual was difficult due to variation in pedestrian characteristics. Therefore, a deterministic and probabilistic approach was used to determine the critical gap. The critical gap was found using Raff's, Greenshield and Ashworth methods (Miller, 1972; Fitzpatrick, 1991) and compared with HCM 2010. The results were presented in Table 5.

Table 3: Traffic Volume and Observed LOS Score from Questionnaire Survey

Sl. No	Name of Crossing	Traffic Volume (PCUs/Hr)		Questionnaire Sample	Observed LOS score					
		Towards Palpannai	Towards Thuvakudi		A	B	C	D	E	F
1.	Thiruverembur	3708	3504	88	16	5	11	6	12	37
2.	Balaji Nagar	2485	2437	57	8	4	8	7	12	18
3.	Kailash	1788	2307	35	3	1	6	3	7	15
4.	Kattur	2230	1744	61	6	12	10	10	10	15
5.	St. Little	2118	2271	55	0	3	5	10	13	24
6.	Kamraj Nagar	3857	3332	88	8	11	11	10	29	18

Table 4: Descriptive statistics of pedestrian characteristics and crossing behavior

Sl. No	Characteristics	Variable	Sample number	% distribution
1	Gender	Male	184	48
		Female	200	52
2	Age	18-30	144	38
		30-55	163	42
		>55	77	20
3	Crossing pattern	Perpendicular	176	46
		L	174	45
		Oblique	20	5
		Angular	14	4
4	Trip Purpose	1	183	48
		2	36	9
		3	81	21
		4	84	22
5	Frequency of Using	1	281	73
		2	11	3
		3	93	24
6	Mobile phone usage	1	5	1
		2	1	0
		3	9	2
		4	7	2
		5	361	94
7	Safety Score	1	40	10
		2	43	11
		3	70	18
		4	93	24
		5	138	36

Table 5: Results of Critical gap estimation using different methods

Critical gap estimation methods	Critical gap (in seconds)					
	Thiruverembur	Balaji Nagar	Kailash Nagar (MB2)	Kattur	St. Little Flowers School	Kamraj Nagar
Raff method	2.40	2.51	2.50	2.54	2.80	2.47
Greenshield method	2.50	2.33	2.50	2.61	3.1	2.44
Ashworth method	2.60	2.57	2.48	2.60	2.91	2.58
HCM 2010 (using observed field values)	9.64	9.77	9.50	9.42	9.62	9.67
HCM 2010 (using default values)	10.27	10.27	10.27	10.27	10.27	10.27

Table 5 gives a comparison of critical gaps using different approaches. Critical gaps were found to be quite low with an extensive deviation between the outcome attained by these four approaches. This has happened because all four methodologies are fully considered homogeneity which is failed to suit for heterogenous traffic conditions. Moreover, the impact of traffic volume is observed as very high with obtained results. From table 5, the estimated critical gap was smaller when compared with critical gap estimated using HCM2010, which depends on pedestrian crossing time alone. In a particular section, transportation planners are required to consider the sufficient number of pedestrian crossing with adequate width to accommodate all pedestrians crossing. As per HCM2010 capacity and LOS values, it required more pedestrians crossing, which will be more challenge in India, where pedestrian activities are predominant.

8. Development of Pedestrian Gap Acceptance Model

The pedestrians crossing behaviour is highly unpredictable to observe from the field. The same pedestrian may not accept the same gap in the same crosswalk since human behavior is inconsistent. The behavior of pedestrians varies according to their age and gender. A correlation test was conducted to select the variables which significantly influence the pedestrian accepted gap. Pearson correlation test was conducted at 95% confidence interval using SPSS software (https://www.ibm.com/analytics/spss-statistics-software). A correlation usually tests the null hypothesis that the population correlation is zero and it is statistically significant if its “Sig. (2-tailed)” < 0.05.

From analysis, gender and rolling gaps were correlated with the accepted gap. Gender and rolling gap values have a p-value less than 0.05. It is inferred that the accepted gap size for males was less than that of females. This could be because they are less safety conscious and ready to take risks when compared to females. From the correlation analysis, the rolling gap was negatively correlated with accepted gap, showing that as rolling gap behaviors increases, the accepted gap size decreases. Rolling gap behavior is the lane by lane crossing of the pedestrian accepting available small gaps. Pedestrians followed rolling crossing when there was a huge traffic volume.

8.1. Gap Acceptance Model Development using MLR

Initially, the MLR method is adopted to model pedestrian crossing behavior at uncontrolled midblock by using significant variables in SPSS software. In the proposed model, the minimum pedestrian gap acceptance value was calculated by considering various pedestrian behavioural characteristics. The MLR model shows an increase or decrease in gap value with respect to the significant independent variables. Thus, the functional relationship between input and output parameters are easily represented in the developed model. To develop the model for estimating minimum gap acceptance, a stepwise linear regression method was adopted by estimating that pedestrian gap acceptance followed a normal distribution. Therefore, the generalized framework of proposed model is given below:

$$Accepted\ Gap = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \quad \text{(Eq 1)}$$

Where X_{1-n}= explanatory variables; β_{1-n}= estimated parameters from the model; β_0= constant. In the developed regression model, the dependent variable is the accepted gap and the independent variables are the different pedestrian and traffic characteristics. Out of the different considered characteristics, gender, age and waiting time became significant after the regression analysis. From the collected data, 80% of data used for model development and remain used for validation. The stepwise MLR was conducted in SPSS software at 95% confidence interval. The results are indicated in Table 6, and the obtained linear regression equation is as follows

$$Accepted\ Gap = 2.351 + (1.290 * \text{gender}) + (0.176 * \text{age}) - (0.026 * \text{waiting time}) \quad \text{(Eq 2)}$$

Table 6: Pedestrian Gap Acceptance model: Estimation of coefficients

Model variables	Unstandardized coefficients B	Unstandardized coefficients Std. error	standardized coefficients Beta	t-value	Sig.
(Constant)	2.351	0.081	-	28.926	0.000
Gender	1.290	0.063	0.732	20.418	0.000
Age	0.176	0.043	0.148	4.903	0.000
Waiting time	-0.026	0.010	0.096	2.663	0.008

The estimated correlation coefficient (R = 0.726) value denotes a good relationship between observed and predicted accepted gap by the developed MLR based model. The model with gender, age, and waiting time as significant variables produced the reasonable R square value. The estimated adjusted R square value was equal to 0.528, or 52.8%, which explained that the model calculated the 52.8% variability in the accepted gap of pedestrians and described by the explanatory variables. Here, this study estimated the mean absolute deviation as 0.61, which is lesser considering the observed accepted gap.

The collected data were divided into two sets, 80% of the data were utilised to develop the gap acceptance model and balancing 20% data utilized for validation of the developed model. The mean absolute percentage error (MAPE) is a measure of the predictive precision of a forecasting technique in statistics. MAPE value was calculated for each observation and in an average MAPE value was obtained as 12.12 %. It can be concluded that the observed values of the accepted gap and predicted values of the accepted gap are quite close, thus the model is reasonably predicting the pedestrian gap acceptance. But the MLR model failed to predict the actual pedestrian crossing behavior by considering various variables. Therefore, this study used ANN techniques for further analysis.

8.2. Gap Acceptance Model using ANN

8.2.1. ANN Model Formulation

In recent days, ANN is a widely used techniques for modelling non-linear data due to predictive ability and system behaviour of this method. ANN architecture has three layers such as input, hidden, and output layer which are interrelated by neurons. In hidden neurons, the activation function is used to develop the relationship of input values with expected output values. Adjusting the connection of every neuron is followed to improve the predictive ability which is followed till reach the higher accuracy level of ANN model (Kadali et al., 2015). The present study implemented an ANN model by adopting a feed forward with the back-propagation algorithm. The number of neurons in the hidden layer was selected by trial and error method to produce the best performance value. In this study, 16 neurons were considered as input layer which indicated the pedestrian, geometric, and traffic parameters and a single neuron was considered as an output layer, which represented the gap acceptance. Weight was considered to represent the strength of each connection. The summation operation of inputs with their respective weights is presented in Eq. 6.

$$\text{SUMn} = \sum_{m=1}^{i} W_{mn} Y_{mn} \qquad \text{(Eq 4)}$$

where W_{mn} represents recognized weight; Y_{mn} indicates input value; SUM_n defines the input to a node in layer n. The back-propagation technique is followed, and a reLU activation function calculates the expected output neuron.

8.2.2. Model Results and Analysis

By adopting ANN technique, the pedestrian gap acceptance model was developed with 4840 gaps of 384 pedestrian data which considered pedestrian accepted as well as rejected gap values by using PYTHON. The rectified linear (reLU) activation function was used for modelling. The data were segregated as 70%, 15% and 15% to perform network training, testing and validation and the process stopped at 1000 epochs for training.

8.2.3. ANN Architecture Development

The best ANN architecture was achieved by adjusting the number of input layers and hidden nodes in the hidden layer. The performance of the model was evaluated by estimating the values of minimum mean square error (MSE) and the maximum correlation coefficient. The success prediction rate of the pedestrian accepted or rejected gap was calculated with 5% confidence interval. Various ANN models were established by increasing the input and hidden nodes with a single output node. Finally, it was found that a model with 3 hidden layers on 10,10,10 neurons produced the best result on gap acceptance prediction.

8.2.4. Importance of Input Variables

The significant influence of input variables with the output parameter was estimated by adopting sensitivity analysis and connection weight approach methods. In the sensitivity analysis, the optimum number of hidden neurons was calculated without considering the prior ANN architecture. By changing the number of neurons, the process was repeated until reaching the optimal number of hidden neurons. By considering the lowest RMSE value, the best ANN model, i.e 13-3-1, was selected as the final result. Rejected gap size, platoon or group size, and path change condition variables were eliminated from the ANN modelling as these were not contributing to the optimum model. The MAPE value of the model yielded a value of 10.3%. The connection weight approach was used to find the importance of each input variable based on the relative importance rate. For calculating the relative importance, the sum was measured against other variables. The relative importance of the best ANN model (13-3-1) is represented in Figure 3. It can be easily concluded that the proposed method provides a more accurate result on the relative importance estimation of each input variable.

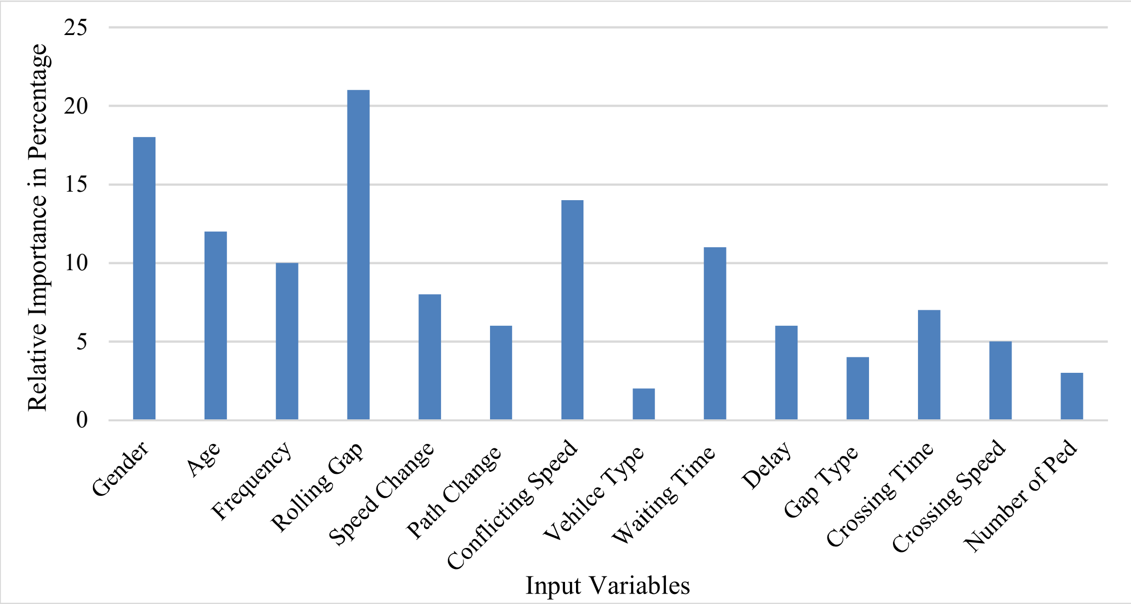

Figure 3: Relative importance of input variables with ANN model of 13-3-1

From figure 3, the pedestrian rolling gap had a higher significant rate followed by gender, conflicting vehicle speed, age, and waiting time. The proposed method failed to give a positive or negative impact of input parameters towards output variables such as gap acceptance.

8.3.Comparison of MLR with ANN-based Model

Two types of modelling techniques such as MLR and ANN were used in this study for predicting pedestrian gap acceptance. Due to basic assumptions and multi-collinearity nature, the MLR model failed to predict the actual gap acceptance behavior. But, these issues were eliminated by adopting ANN technique. Based on R-Square and MAPE value comparisons, ANN was performing better than the MLR for estimating pedestrian gap acceptance at midblock under heterogeneous traffic conditions. For identifying significant variables, ANN modelling is appropriate, but for the quantification of variables MLR is found suitable technique.

9. Development of Pedestrian Level of Service Model

This study sought to mathematically express the pedestrian crossing behavior that affects the pedestrian perceived level of service at mid blocks. The following three-step process was applied to develop the PLOS model:

1. Identify the significant variables by performing correlation tests
2. Estimate the coefficients for the input parameters that produce an accurate model fit
3. Perform the validation with field data

All possible variables were tested for model development under the stepwise regression process. By conducting the Pearson correlation test, the following parameters were considered in developing the LOS model: traffic volume, pedestrian accepted gap and pedestrian waiting time. Other variables were not considered due to poor correlation. The selected variables indicate the best surrogate measures for representing complex operation conditions. A total of 384 samples were used for model development and validation. A stepwise regression analysis technique was adopted using SPSS. The results are represented in Table 7 and the expression of LOS model is explained in Eq 5.

Table 7: PLOS model coefficients and Statistics

Variables	Coefficients	Std. Error	t-value	sig. value
Constant	-0.325	0.223	-1.455	0.150
Traffic volume (TV)	0.001	0.000	9.972	0.002
Pedestrian accepted gap (Gap)	1.197	0.055	21.692	0.000
Pedestrian waiting time (WT)	0.008	0.003	2.398	0.019

The following model format is developed to estimate PLOS:

$$PLOS = 0.008 * WT + 1.197 * Gap + 0.001 * TV - 0.325 \quad \text{(Eq 5)}$$

The LOS score with respect to each category was estimated using the midpoint technique and the results were explained in Table 9.

Table 8: Level of Service Categories

PLOS Category	Model Score
A	< 1.5
B	>1.5 and 2.5
C	> 2.5 and 3.5
D	> 3.5 and 4.5
E	> 4.5 and 5.5
F	> 5.5

Table 7 represented the variables, coefficients, t statistics and p-value for the developed LOS model. The coefficients were significant at 95% confidence interval. The R-Square of the best-fit model was found to be 0.8780. From the collected data, 80% of data were utilized for developing a model, and remain 20% of data utilized for validating the proposed model. The calculated statistical values of Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), Pearson's R and R^2 were found to be 8.07%, 1.6160, 0.8081, and 0.7371 respectively. The values are less in error, and it indicates that the predicted LOS scores were close to denote the field situations of specific mid-block under mixed traffic conditions.

10. Multicriteria Decision Making Using Weighting by Ranking Method and Analytical Hierarchy Process (AHP)

10.1. Multiple-criteria decision-making (MCDM) Methodology

There were seven steps followed in MCDM methodology. Finally, one or more of the best alternatives were chosen for further analysis. The factors which influence pedestrian crossing behaviour were collected during a field survey. These were ranked on a priority basis. By adding weighted score of all variables, the composite scores were obtained which were used to rank the variables in ascending order. Weighting by the ranking method was used only as a preliminary step to narrow down the choices. Weighting by the ranking method was carried out separately for all six mid-block crossings. For crossing the road, safety was considered as the main factor by pedestrian followed by comfort, less time and easy access at Thiruverembur mid-block crossing. The traffic signal was considered as the most preferred crossing facilities in Thiruverembur followed by zebra crossing, pelican crossing, footbridge, pedestrian speed table and underpass mid-block crossing. The similar procedure is followed for all other five locations data.

10.2. Analytical Hierarchy Process (AHP)

AHP is a multi-criteria decision-making approach and was presented by Saaty in 1977 and 1994. The weighted average rating for all the decision alternatives was developed and the highest scored alternative was chosen as the optimal solution. The AHP processes were presented for only Thiruverumbur location data in Table 9 to 11.

Table 9: Develop weights for criteria in Thiruverembur

Conditions	Safety	Comfort	Less time	3rd root of product	Priority vector
Safety	1	3	7	2.76	0.68
Comfort	1/3	1	2	0.87	0.22
Less time	1/7	1/2	1	0.41	0.10
Sum	1.48	4.5	10	4.04	
Sum * PV	1.01	1	1		
λmax	3.01				
CI	5*10^(-3)				
CR	0.009				

Table 10: Develop ratings for each decision alternative with respect to safety

Facilities (Safety)	Traffic signal	Zebra crossing	Pelican crossing	3rd root of product	Priority vector
Traffic signal	1	3	1/4	0.91	0.23
Zebra crossing	1/3	1	1/5	0.4	0.09
Pelican crossing	4	5	1	2.71	0.67
Sum	5.33	9	1.45	4.02	
Sum * PV	1.2259	0.81	0.9715		
λmax	3.01				
CI	5*10^(-3)				
CR	0.009				

Table 11: Weighted average rating in Thiruverembur

Criteria	Safety	Comfort	Easy Access	Weight
Facility	0.68	0.22	0.10	
Traffic Signal	0.23	0.23	0.16	0.223
Zebra Crossing	0.09	0.67	0.54	0.263
Pelican Crossing	0.67	0.10	0.29	0.507

The one with the highest score is the pelican crossing which is chosen as the best approximate solution to the crossing facility in Thiruverembur. Likewise, the pedestrian preference was calculated for another five study locations using AHP methods. From the AHP analysis, the traffic signal was preferred facilities by pedestrian at three locations such as Balaji Nagar, St. Little Flowers School, and Kamraj Nagar midblock. Zebra crossing facility was considered as the most preferred facility by pedestrian at Kailash Nagar (MB2), and Kattur midblock locations. Pelican crossing was rated as the most preferred choice by pedestrian at only Thiruverembur midblock location. The identified solution will be useful to improve the perception of pedestrian safety at selected study locations. Thus, the proposed AHP framework will be useful to prioritize the various facilities or polices for implementing on the field.

11. Conclusions

Six locations within the city of Trichy, where there was considerable movement of pedestrians and traffic, were selected for this study. Data was collected using video-graphic and user perception surveys. The pedestrian and traffic characteristics were extracted from the collected video. Descriptive analysis was performed to understand pedestrian actual crossing behavior. The pedestrian critical gap at each location was estimated adopting Raff's, Greenshield, Ashworth methods and compared with the standard manual. Correlation analysis was performed to select the variables which influence the gap acceptance behavior of pedestrians. In this study, MLR modelling along with a non-linear modelling such as ANN was carried out to model pedestrian gap acceptance. The models were validated using a cross validation test. Followed by Pedestrian LOS model was developed and validated using MLR technique. Finally, pedestrian preference on facilities were ranked using AHP approach. The following key findings were drawn from this study:

- The waiting time was highest for >55 age group and least for 18-30 age group whereas the crossing speed was highest for 18-30 age group.
- The majority of pedestrians followed perpendicular and L shaped crossing pattern. Illegal crossing patterns like oblique and angular were followed mainly by males.
- The correlation analysis result shows that the significant variables that affect the gap acceptance behaviors are gender and rolling gap.
- The variables that were found significant using the stepwise MLR model were age, gender and waiting time. The adjusted R square value yielded a value of 0.524.
- During sensitivity analysis, the best ANN architecture was finalized by adopting the missing variable method. From ANN architecture, a model with 13 input variables gave a better prediction for accepting gap size based on minimum RMSE.
- The R square value yielded a value of 0.792 using ANN modelling. Rolling gap and vehicle conflicting speed were found to be contributing factors.

The present study conducted in mid-block crossings can be broadened to a wider study area, including unsignalised intersections. The results of the pedestrian crossing analysis can be useful in developing future crossing facilities with better safety. In planning of more pedestrian facilities, ANN modelling can be used due to its capable to incorporate more input parameters on output variable. The study has various limitations to solve in the future research scope. The number of children and aged pedestrians was low as compared to other groups. The pedestrian movement in peak hour is only considered for modelling pedestrian crossing behavior. Due to the obstruction of heavy vehicles, few pedestrian crossing behaviours were overlooked, which caused the visibility difficulties in the data extraction process. For identifying significant variables, ANN modelling is appropriate, but for the quantification of variables, MLR is found suitable. As a future study, the authors suggest to increase the sample size and compare the behavior with different cities with the different pedestrian, traffic and geometric conditions for assessing the proposed model transferability.

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