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QUANTITATIVE APPROACH TO DETERMINE PEDESTRIAN DELAY AND LEVEL OF SERVICE AT SIGNALIZED INTERSECTION

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Abstract

Purpose: Level of Service is a widely adopted terminology to determine the efficiency of any transport system. From the literature it was studied that the multiple linear regression models established by many researchers to determine PLoS evolved with addition or removal of one or more physical parameters or with respect to the perception of users from different locations. At an intersection, there is little or no established methodology developed so far to determine a quantitative approach for PLoS similar to Vehicular Level of Service (VLoS). It was also pointed out that under heterogeneous traffic conditions, pedestrians are most vulnerable at intersections and they share the same space with motorized vehicles for crossing movements.

Methodology: Thus, this study was built on the hypothesis that pedestrian delay of a signalized intersection is quantitatively dependent on pedestrian volume, vehicular volume and cycle time. Two signalized intersections operating as fully actuated and fixed cycle time were considered for study for period of four hours each, covering two hours of morning peak and off-peak hour traffic data.

Main Findings: Using various statistical techniques, an empirical model was developed between the pedestrian delay and independent variables namely cycle time, pedestrian volume and vehicular volume. PLoS range was also determined through k-means clustering technique.

Implications: The empirical model developed was validated and the application of this research was also explained.

Novelty: The study is a new quantitative approach to determine PLoS and was limited to two intersections. Increase in the data may improve the accuracy of the model.

Keywords: Empirical Model; Pedestrian Level of Service; Pedestrian delay; Vehicular Volume; Cycle time.

INTRODUCTION

More and more motorized vehicles on roads in limited road space resulting in congestion and increased pollution levels has led to increasing demand for the use of non-motorized transport, public transport and green vehicles. Even to make public transport a success, there should be unhindered pedestrian facility including wide footpaths, ramps, crossing facilities, good quality of pavement etc. Planning and design of pedestrian facilities encourages more and more people on foot. But as these pedestrians reach the road intersection from a comfortable and safe footpath, they become vulnerable while crossing the intersection.

Level of Service (LoS) is computed to qualitatively measure the effectiveness of a service provided to the users. Although many studies are conducted on Pedestrian Level of Service, there is little or no established method to determine Pedestrian Level of Service (PLoS) at signalized intersection, similar to Vehicular Level of Service (VLoS). Most of the studies on pedestrian level of service concentrate on the physical dimensions like the width of footpath, the crossing facilities, obstructions, pavement conditions, materials laid, space at corner, ramp details, flow rate, walking speed, improvement in bicycle facilities etc. These parameters are service measures and improve the comfort and safety of users, which are important and much needed but these do not often give a clear picture in determining the LoS. The Pedestrian Level of Service (PLoS) changes with different physical dimensions considered for the pedestrian movements.

The standard parameters to determine the vehicular level of service at a signalized intersection are considered to be control delay and volume to capacity ratio. There are few quantitative methods established to determine the pedestrian level of service similar to vehicular level of service of a signalized intersection. Other than the physical parameters, pedestrian delay is a function of signal timing and is also directly dependent on the vehicular volume and pedestrian volume. The objective of the study is to understand the best empirical model for determining the pedestrian delay considering cycle time, pedestrian volume and vehicular volume as the independent variables. Two case studies of signalized intersections are considered for analysis functioning under different operating conditions. The study also determines pedestrian level of service at signalized intersection with respect to pedestrian delay based on k-means clustering technique.

LITERATURE REVIEW

A number of related studies were reviewed to appreciate the factors affecting the pedestrian level of service. These are described briefly as under:

HCM 2010 has developed Pedestrian Level of Service (PLoS) score for the intersection for evaluation of the performance of crosswalks. This score is determined on the basis of travellers' perception. The quality of service for a specific trip through a signalized intersection is rated by the users on the basis of their travelling experience. The methodology thus provides a procedure for empirically developing the performance measures into a score. The equation presented below can be used to measure the Pedestrian Level of Service score.

$$PLoS\ score,\ I_{p,int} = 0.05997 + F_w + F_v + F_s + F_{delay}$$

where $I_{p,int}$= pedestrian LoS score for intersection., F_w = cross-section adjustment factor, F_v = motorized vehicle volume adjustment factor, F_s = motorized vehicle speed adjustment factor, F_{delay}= pedestrian delay adjustment factor. Archana.G and Reshma E.K (2011) has also shown an analysis of pedestrian level of service at signalized intersection cross walk by considering one dependent and seven independent factors. The researchers conducted a questionnaire survey to score the crosswalks in terms of safety and comfort. The authors developed the regression equation as presented below to determine the PLoS score and also came up with a PLoS score table.

$$PLoS=7.44 - 0.002PFH - 0.061PCT + 0.679CSR$$

where CSR = crosswalk surface condition ration (0 – poor, 1 – moderate, 2 – good); PCT = pedestrian crossing time (sec); PFH = pedestrian flow (ped/hr). Thambiah Muraleetharanet. al. (2005) identified the factors affecting PLoS at intersections. Three factors were used to develop a statistical relation which measures the conditions of crosswalks at intersection.

$$Pedestrian\ LoS\ at\ crosswalk = 7.842 + \sum_{i=1}^{3}\sum_{j=1}^{3} D_{ij}\delta_{ij} - (0.037x\ pd) - (0.0031\ x\ pb)$$

Where D_{ij} = categorical score associated with j^{th} level of the i^{th} attribute, δ_{ij} = 1 if the j^{th} level of the i^{th} attribute is present, pd = pedestrian delay in seconds, pb = number of pedestrian-bicycle interactions. Axel Wilke et al. [18] (2011) has developed a methodology to measure existing LoS for pedestrian crosswalk and to allocate a score for LoS score, considering pedestrian crossing distance, delay, green time ratio and risk as the criteria to score LoS. The study also identified different measures to improve PLoS. Xuan Wang and ZongTian (2010) came up with the concept of pedestrian delay model with a two-stage crossing design. The model indicates the significance of pedestrian platoon in determining the average pedestrian delay. They recommended the platoon dispersion study in the delay model. Singh K and Jain P.K. (2011) made a comparative study of different methodologies developed by various researchers to determine the pedestrian level of service. They concluded that current methodologies are not universally applicable as they are unable to evaluate the entire spectrum of pedestrians. Soren Underlien Jensen (2012) developed a log it regression model to measure the pedestrian and cyclist satisfaction while crossing the road. The width and height of pedestrian and bicycle facility, length of crossing, width of roadway, traffic volume, waiting time and speed limit were the variables considered to develop the model.

CASE STUDY AND DATA COLLECTION

Two intersections were considered for this study purpose. One was Pattom junction located at Thiruvananthapuram, the capital city of Kerala. Kerala is a state in the south-western coast of India. Pattom intersection is one of the busiest junctions in Thiruvananthapuram, characterised by the presence of two schools, one hospital and several office and residential buildings in the vicinity. This, four arms - at grade - fixed time signalized intersection does not offer separate signal phase for pedestrian crossing. Nearly one lakh vehicles cross Pattom Junctioneveryday (92,150 vehicles per day) as per the 2010 - 2011Annual Report by NATPAC. All the arms offer straight, right and left turning traffic movements, with provision of zebra crossing at the mouth of the junction.

The second case study intersection identified for the study was Rambagh Intersection, which is located at Jaipur, the capital city of Rajasthan. Rajasthan is located in the western side of India. Rambagh intersection is one of the busiest junctions in Jaipur, characterised by the presence of a school, a college, one hospital and several office and residential buildings in the vicinity. This, four arms - at grade – fully actuated signalized intersection does not offer separate signal phase for pedestrian crossing. Peak hour traffic volume at this junction is 21,457 PCUs as per Comprehensive Development Plan for Jaipur, 2010 prepared by Jaipur Development Authority. All the arms offer straight, right and left turning traffic movements, with provision of zebra crossing at the mouth of the junction. Figure 1 presents the survey images of the two signalized intersections under study.

Four-hour videography survey was conducted at the intersections covering the morning peak and off-peak hour traffic. Video camera was fixed at a suitable vantage point from where the movement of pedestrians and vehicles and their interaction were captured clearly. The methodology of this paper is structured as shown in Figure 2.

DATA CODING

Data collected included pedestrian volume, pedestrian delay, vehicular volume and cycle time of two signalized intersections under study operating under fixed time and fully actuated signal control system. Data coding in every 5 second interval was undertaken for the purpose of analysis. Data was decoded for vehicular volume, pedestrian flow and pedestrian stopped delay per cycle time per direction of flow (pedestrian traffic in all direction of crossing movement was considered, which comprises of 12 directional crossing) per intersection under study. Vehicular volume was coded for

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different modes comprising of two wheelers, three wheelers, small car, big car, and Light Commercial Vehicles (LCV), Heavy Commercial Vehicles (HCV), buses, bicycle and cycle rickshaw. Vehicular volume was converted into dynamic Passenger Car Unit (PCU) values based on the optimization model adopted from Indian Highway Capacity Manual. Pedestrian delay is classified into two categories – i) due to signal phase delay and ii) due to interrupted delay caused by motorized vehicles at crossing. From this coded data, weighted average stopped delay of pedestrians per cycle time was computed per approach arm and then for the whole intersection compiling all the approach arm of the intersection. The traffic data characteristics of peak hour and four-hour survey period of both the study intersections are presented in Table 1.

Figure1: Snap shot of study intersections; Pattom Junction, Thiruvanathapuram, Kerala and Rambagh Intersection, Jaipur, Rajasthan.

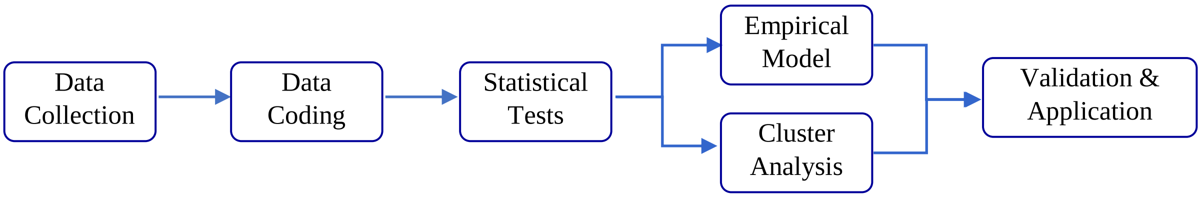

Figure 2: Flowchart presenting structure of the research

STATISTICAL TESTS – RELATIONSHIP BETWEEN PARAMETERS

The performance measures considered for the analysis were pedestrian delay, vehicular volume, pedestrian volume and cycle time, where pedestrian delay is the dependent variable and the rest are independent variables. The aim of the study is to statistically determine the best suited relationship between various parameters which determines the pedestrian delay of signalized intersection. Data from both the case study signalized intersections are considered comprising all the approach arms of each intersection, to determine the empirical model; thus, the model incorporates varying cycle time and different signal operating characteristics. A total of 203 observations during a period of 4 hours were considered from the study intersections. In order to determine the best fit relationship between the performance measures – pedestrian delay, pedestrian volume, vehicular volume and cycle time - different statistical tests were attempted.

The Normality test was conducted for each parameter and the p-value obtained after the test should be greater than 0.05 to satisfy the normality test. Here in this study, the results showed that the variables were following a non-normal distribution. The reason for this is due to the skewed nature of variables, as the data is concentrated for a defined time of four-hour period. From the total 203 observations, 10% of outliers from data were removed statistically. Thus, for the development of empirical model, a total of 183 data points was considered. The correlations between the variables were documented using Spearman's Rank Correlation method. As a rule of thumb, ± 1.0 to ± 0.5 are considered to have a strong correlation,± 0.30 to ± 0.49 moderate correlation, below ± 0.29 weak correlation and zero value gives no correlation between the selected two variables. When the test result gives a negative value, it indicates that the selected variables have negative correlation. Table 2 below presents the correlation matrix between the variables using Spearman's Rank Correlation method along with the p-values obtained. In these correlation tests, the p-values should give a value less than 0.05 to obtain apposite result. It was observed from the correlation analysis presented in Table 2 that pedestrian delay shows a satisfactory correlation with vehicular volume and cycle time; and a poor correlation with pedestrian volume. Also, vehicular volume shows a strong correlation with cycle time.

Since the parameters did not satisfy normal distribution, further analysis was based on non-parametric tests. Kruskal-Wallis test was conducted which is an alternative to ANOVA for normally distributed variables to compare the independent variables with the dependent variable. The p-value obtained from the test was below 0.05 which satisfies the condition leading to a strong non-parametric relationship between the performances measures considered. Pedestrian delay was considered to be the dependent variable while pedestrian volume, vehicular volume and cycle time are taken as the independent variables for the analysis throughout. Further statistical analysis was conducted to determine the best fit distribution function of the parameters considered. From the different distribution tests, it was inferred that the dependent parameter, pedestrian delay, consistently follows Logistic and Weibull distribution when compared to other distributions. Table 3 presents the best fit distribution functions for the variables considered for analysis.

COMPREHENSIVE EMPIRICAL MODELS

Based on the distributions tests, logistic and log-linear regression analysis were considered further to determine the most appropriate empirical model and the best model was selected from the two. The criteria for the selection of the best model was the one which provides satisfactory R^2 value and Root Mean Square Error (RMSE) value between the observed and the predicted results with acceptable Standard Error value along with Akaike's Information Criteria (AIC) and Schwarz's Bayesian Criterion (SBC) values. Table 4 shows the Goodness of fit statistics, RMSE and the median of the standard error value of estimated models using Logistic Regression and Log-Linear Regression.

To strengthen the model, percentage error of the model was also determined using the equation (Predicted value - Observed value) / Predicted value*100. The percentage error for the two models were estimated as 0.152% and 9.5% for log-linear and logistic models respectively. It is inferred from Table 4 that R-squared value is higher for logistic regression model than log-linear regression model. But, the AIC and SBC values are lower for log-linear regression models along with less Root Mean Square Error Value. It was also observed that there is distinguishable difference in the percentage error values between the two models where predicted values obtained through log-linear regression analysis gives less percentage error. Thus, from the above inference it can be concluded that log-linear regression analysis gives the best fit empirical model between the performance variables pedestrian delay, pedestrian volume, vehicular volume and cycle time of signalized intersections. Equation (1) presents the estimated log-linear regression model between the parameters. The observed and predicted values of pedestrian delay is represented in graphical form as shown in Figure 3. It also demonstrates the lower and upper bound values for pedestrians delay as well.

$$PD = e^{(1.352+0.00252*CT + 0.00447*PV + 0.00469*VV)} \qquad \text{eq. (1)}$$

where, PD = Pedestrian Delay,

CT = Cycle Time,

PV = Pedestrian Volume,

VV = Vehicular Volume,

CLUSTER ANALYSIS AND LEVEL OF SERVICE

Cluster analysis is a multivariate method used to classify observations in classes (clusters) on the basis of a set of measured variables such that similar variables are placed in the same group. To get the most accurate result, values of pedestrian delay measured from all the approach arms of the intersection were considered for cluster analysis. This covers the delay value of each pedestrians using the intersection per cycle time. 812 data points were obtained with respect to eight approach arms from two signalized intersections. Amongst the different clustering techniques, K-means clustering method is the most appropriate for the selected data set based on the type of input variable, number of input variables, selection of class and on the fact that k-means cluster analysis presents deterministic result. The 98th percentile of the data set was determined and the data points greater than 98th percentile was removed statistically so that few extreme points do not influence the clustered class data. Silhouette Coefficient (SC) analysis and One Sample Runs Test – upper tailed for each cluster range was carried out until the convergence between two consecutive class becomes small. The SC values close to one indicates strong association of clustered classes and zero indicates least association of the clustered classes. One Sample Run Test was carried out to test the randomness of variables within a class. The p-value obtained from the one same run test should be greater than 0.05 to justify the cluster range obtained.

The data sets were clustered to obtain a possible cluster range varying from four to seven. Cluster seven demonstrated high Silhouette Coefficient values with 0.63, 0.81 and 0.73 as minimum, maximum and average values respectively. Cluster 4, 5 and 6 had an average SC value of 0.701, 0.714 and 0.711 respectively. Figure 4 presents the SC values for different clusters ranging from four to seven clustered classes. From the SC values it is observed that cluster 7 is estimated as the best number of clustered class that can be obtained from the pedestrian delay data set. From the seven clustered classes, each class was put through the one-sample run test. All the seven numbers of clustered classes satisfied the required criteria of p-value greater than 0.05, thus accepting the null hypothesis that the values in each class range are randomly distributed.

From this analysis, seven level of service ranges have been estimated for pedestrian delay, against the six level of service ranges studied from literature. Table 5 presents the level of service category, pedestrian delay range, level of service condition, cluster centroid value of level of service ranges and one sample run test values for the clustered classes of pedestrian delay. The k-means cluster analysis results for the pedestrian delay values from the survey analysis are grouped into seven ranges, A to F_2; A offers the best while F_2 shows the least LoS notation. The delay range which is greater than

35 seconds is categorized into level of service F and further broken into level of service F_1 and F_2 for range between 35 – 45 seconds and greater than 45 seconds respectively. Greater than 45 seconds of delay for pedestrians are often considered as failed condition since the pedestrians would not prefer to wait at the intersection for longer time period and they will find a gap between the motorized vehicles to cross the intersection risking their life. Improvement measures must be undertaken from the range D to E where the level of service change from unsatisfactory to poor condition. Figure 5 shows the range of LoS through cluster analysis using pedestrian delay in seconds.

MODEL VALIDATION AND APPLICATION

For the purpose of validation, operating characteristics of Rambagh Intersection was changed from fully actuated to fixed signal cycle time and videography survey was conducted. Peak 15 minutes data was decoded from morning 9.15 am to 9.30 am of this intersection. These data were not considered for model development or for any previous analysis in this study. Table 6 presents the results obtained through validation of equation (1) considering the observed data for cycle time, vehicular volume and pedestrian volume as presented in columns (2), (3) and (4) respectively. The predicted delay values obtained from equation (1) is presented in column (6) Table 6. These predicted values are then compared with observed pedestrian delay from filed data, given in column (5) of Table 6. RMSE value determined with respect to the observed and predicted value is 5.39. These RMSE values are acceptable since this RMSE value doesn't show a radical difference from the RMSE value of the predicted model. This proves the hypothesis of this study, that the pedestrian delay of signalized intersection is a function of cycle time, pedestrian volume and vehicular volume. The same model can be applicable for intersections with similar operating characteristics, vehicular volume and pedestrian volume.
Further explaining the application of this research, the average predicted pedestrian delay estimated from the data under validation using equation (1) is obtained as 18.733 sec. From Table 5 Pedestrian Level of Service obtained for 18.733 sec is LoS D. Thus, this research is helpful to determine pedestrian level of service at signalized intersection considering pedestrian volume, vehicular volume and cycle time under mixed traffic condition.

CONCLUSION

Through literature review, the study has identified research gaps and aimed to develop a methodology to quantitatively determine the Level of Service for Pedestrians at signalized intersections. Most of the researches on PLoS conducted are based on the service associated variables, which is a qualitative approach to determine PLoS. The variables considered are then scored, based on the utility factors and finally a score model is developed to determine the pedestrian level of service. But this score value varies as new relation is discovered between variables or with the addition or removal of variables. This study develops a quantitative empirical model between pedestrian delay and other performance variables. Two four-arm fixed time signalized intersections were considered for this study. Different relations between variables were tested and the best fit empirical relationship was developed. Empirical model was developed considering pedestrian delay as dependent variable and vehicular volume, pedestrian volume and cycle time as the independent variables. The best model determined is validated using field observed data related to vehicular volume, pedestrian volume and cycle time values. Cluster analysis has been carried out by considering pedestrian delay, which in turn resulted in the development of defined clusters falling in different range values for the pedestrian level of service on basis of delay.

LIMITATION AND STUDY FORWARD

The analysis is carried out on data collected for duration of four hours on account of limited manpower. The same analysis can be repeated for a larger survey data, for better accuracy of result.

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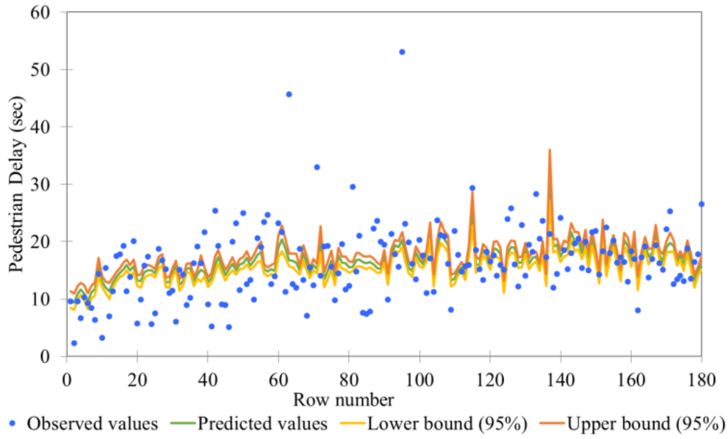

Figure 3: Plot of observed and predicted pedestrian delay values using Log-Linear Empirical Model.

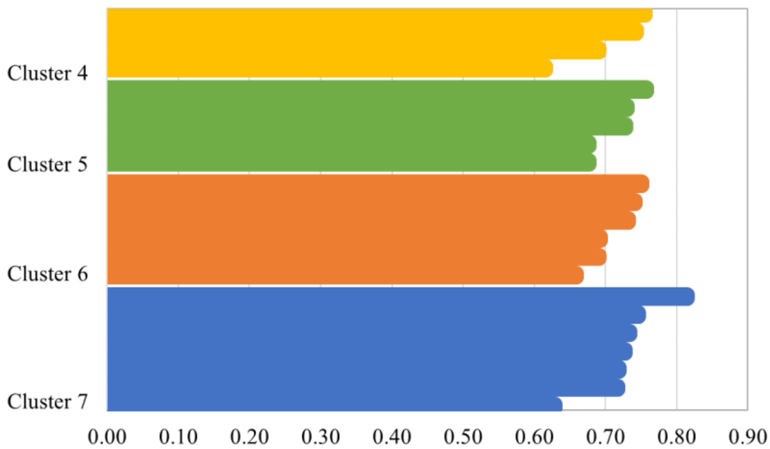

Figure 4: Silhouette Coefficient values for different clusters ranging from four to seven clustered classes

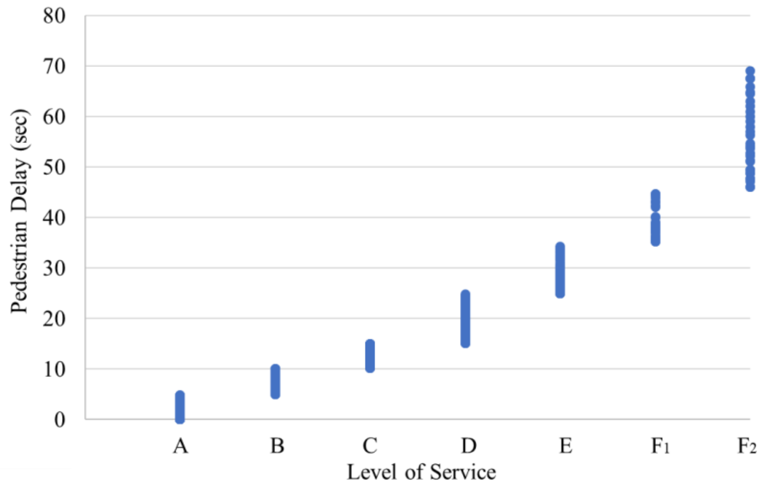

Figure5: Clustered Level of Service based on Pedestrian Delay in seconds

TABLE 1: Peak Hour and Four-hour survey period traffic data for the case study intersections.

Intersection	Vehicular Volume (PCU/hr)	Pedestrian Volume	Cycle time range (sec)	Average Vehicular delay (sec)	Average Pedestrian Delay (sec)	Number of traffic signal cycles.
Traffic Characteristics of Study Intersection _ Peak Hour Data						
Pattom Intersection	6,134	844	120	51	20	30
Rambagh Intersection	5,686	1432	115 - 180	83	19	26
Traffic Characteristics of Study Intersection _ Four-hour Data						
Pattom Intersection	20,734	3,200	120	49	18	109
Rambagh Intersection	27,849	4,715	115 - 185	90	18	94

Source: Survey Analysis

TABLE 2: Spearman Rank Correlation Matrix and p-values

Spearman's Correlation matrix and p-values								
	Correlation values				Spearman p-values			
Variables	Cycle Time	Pedestrian Volume	Vehicular Volume	Pedestrian Delay	Cycle Time	Pedestrian Volume	Vehicular Volume	Pedestrian Delay
Cycle Time	1	-0.145	0.677	0.358	0	0.051	<0.0001	<0.0001
Pedestrian Volume	-0.145	1	0.118	0.150	0.051	0	0.111	0.044
Vehicular Volume	0.677	0.118	1	0.370	<0.0001	0.111	0	<0.0001
Pedestrian Delay	0.358	0.150	0.370	1	<0.0001	0.044	<0.0001	0

Note: Values in bold shows significant results.

TABLE 3: Distribution tests and p-value of analytical parameters considered for the study.

Sl. No:	Distribution	Parameters			
		Pedestrian Delay	Pedestrian Volume	Vehicular Volume	Cycle Time
1	Exponential	<0.0001	<0.0001	<0.0001	<0.0001
2	Gamma	<0.0001	<0.0001	<0.0001	<0.0001
3	Log-normal	0.047	0.046	0.045	<0.0001
4	Logistic	1.000	0.605	0.976	<0.0001
5	Weibull	0.283	0.790	0.147	<0.0001

TABLE 4: Goodness of fit statistics, RMSE and median of standard error value from estimated models.

Goodness of fit	Pedestrian Delay = f (Vehicular Volume, Pedestrian Volume and Cycle Time)	
	Logistic Regression	Log-Linear Regression
R^2 (McFadden)	0.115	0.104
R^2 (Cox and Snell)	0.727	0.385
R^2 (Nagelkerke)	0.727	0.388
AIC	2181.008	769.711
SBC	2748.118	782.527
Iterations	6	4
RMSE	9.184	5.898
Standard Error	0.788	0.177

TABLE 5: Level of Service classes for Pedestrian Delay, Cluster Centroid and One Sample Run test value are presented.

Class / Cluster	Pedestrian Delay LoS Range (sec)	Condition	Cluster Centroid _ Pedestrian Delay	One Sample Run test
A	0 – 5	Very Good	1.023	0.163
B	5 – 10	Good	7.352	0.759
C	10 – 15	Satisfactory	14.409	0.810
D	15 – 25	Unsatisfactory	19.681	0.460
E	25 – 35	Poor	27.279	0.872
F_1	35 – 45	Very Poor	38.126	0.082
F_2	> 45	Failed	55.433	0.277

TABLE 6: Model Validation

Sl. No. (1)	Cycle Time (2)	Vehicular Volume (3)	Pedestrian Volume (4)	Observed Pedestrian Delay (5)	Predicted Pedestrian Delay using Model, **PD = $e^{(1.352+0.00252*CT + 0.00447*PV + 0.00469*VV)}$** (6)
1	155	190	15	9.9	14.9
2	155	186	9	8.1	14.2
3	155	211	27	18.2	17.3
4	155	315	33	21.4	29.0
5	155	202	38	15.1	17.5
6	155	239	24	12.6	19.5
RMSE Value between observed and predicted values					5.39

