DEVELOPMENT OF PEDESTRIAN LEVEL OF SERVICE (PLOS) FOR JAYWALKING PEDESTRIANS AT UNSIGNALISED INTERSECTIONS ON URBAN ARTERIALS USING ANN & CLUSTERING: A CASE STUDY IN INDIA

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Resume

In a developing country like India where jaywalking is prevalent than using designated crosswalks, pedestrian safety is a major concern. Development of pedestrian level of service (PLOS) is essential for monitoring pedestrian safety for these manoeuvres. The present research incorporates a new methodology to evaluate pedestrian LOS for jaywalkers. The study is conducted in a smart city of Bhubaneswar in India. The pedestrian crossing speeds ranged from 0.6 to 1.4 m/s. Artificial Neural Networks (ANN) are used to determine the pedestrian crossing speeds from vehicular and pedestrian counts whose outputs are close to the field data. A 2-step K-means clustering technique is employed to determine the Pedestrian LOS ranges based on pedestrian crossing speeds. Urban planners, transportation engineers, and legislators can use the methodology to determine PLOS levels to create the pedestrian-friendly infrastructure.

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1 Introduction

Globally, numerous pedestrians lose their lives or suffer serious injuries in vehicular crashes every year. Accidents primarily take place in populated regions. The interaction between the moving vehicles and pedestrians is the cause of this. These road crashes are very expensive for both the victim and society. Every country‘s traffic and transport infrastructure have a big impact on how it develops [1]. Therefore, ensuring pedestrian safety and welfare is a key component of urban planning and transportation management. A useful tool for evaluating and regulating the quality of walking conditions in this situation is the idea of pedestrian level of service (PLOS), which encourages safe and effective pedestrian movement [2].

According to [3], the time taken by the low priority movements (here, pedestrians) to cross an unsignalized intersection serves as a performance indicator for them. The time difference between an actual and ideal operating time for these pedestrians is usually termed as delay, and it is a popular quality of service statistics for junctions. Prior studies have found a connection between traffic conflicts and service delays [3]. Secondly, in developed countries, unsignalized crossings are often managed by signs that determine the priority of different movements, which reduces the probability of conflicts. However, in developing countries like India, where the roads are already burdened by mixed traffic movements with no lane discipline, the traffic flow scenario at unsignalized intersections paint a grimy picture. The majority of unsignalized junctions lack a stop or yield sign, and even those that do, are frequently ignored by vehicles travelling through them [1]. In addition, the pedestrians who cross these intersections do not normally use the designated cross walks and frequently jaywalk. According to [4], LOS is the quantitative stratification of a performance measure or set of performance measurements that reflect service quality. The standard practice establishes six service levels, ranging from A to F, which represent the highest and worst service quality, respectively [5].

There have been much early research focusing on pedestrian safety, and development of Pedestrian LOS/

PLOS, which also has recently come up in [4]. Many studies have focused developing PLOS for sidewalks or at midblock sections [6-11], whereas crosswalks have found very little attention. Even in [12], a speed-based PLOS is established, however, considering speeds of pedestrian above 1.2 m/s as LOS A may not be a correct range, as the average speeds of pedestrians in various countries range from 0.53 m/s in Malta to 1.73 m/s in Denmark [13]. Thus, for every country, and for every type of pedestrian facilities, these ranges need to be different. Authors of [14] developed a new methodology to determine the Pedestrian Crossing Level of Service (PCLOS) for urban areas. Their methodology utilised the geometric infrastructures like kerbs, islands, zebra crossing to assess the PCLOS and not the vehicle and pedestrian behaviour and dynamics. In [15] is studied the perception of pedestrians in general to determine PLOS and didn't limit to any specific traffic infrastructure. A similar perception-based study for pedestrian was also conducted in [16] in Greece. The PLOS on sidewalks, considering Random Forest model, was determined in [17]. Many studies have also attempted to assess pedestrian safety with the help of surrogate safety measures like Anticipated Time to Collision (ACT), Post Encroachment Time (PET), Time to Collision (TTC), etc. [18-20], but the studies have largely been regarded as a substitute for actual investigation. Further, these studies mostly have revolved around highways and expressways. In [21] is developed a pedestrian fatality prediction model using the logistic regression and boosted trees for a city in India, however the factors attributed was just the perpetrator vehicle category. The volume on the road or speed was not considered much, as it was based on crash data only. Cafiso et al. in [22] developed a pedestrian risk index (PRI) to identify the severity of pedestrian-vehicle collision effects. In comparison to sidewalks and walkways, the pedestrian speeds are much higher at crosswalks. According to [23], pedestrians should wait 90 seconds before attempting an illegal crossing manoeuvre. These values are too high, mainly when the pedestrians are of relatively younger age (teenagers or adolescents) and are going to work or attend classes. The PET interaction threshold that was chosen at 20 seconds by [24] also seems very high in today's traffic scenario. A study by authors of [25] detailed that the unauthorised crossing/jaywalking is quite serious near intersections. The past studies reflect that the parameters covered to assess the LOS and safety of pedestrians are usually the geometric features or the volume of pedestrians. Secondly, crosswalks have not been studied much as jaywalking is common in developing countries like India, and therefore it is difficult to assess their safety or determine their LOS. Moreover, the pedestrian and vehicular dynamics are not considered much in past studies.

Therefore, the present study is focused on development of a PLOS model for crosswalks at unsignalized intersections that uses motorised traffic volume, pedestrian volume, and pedestrian speeds as factors influencing the pedestrian safety. The outcomes of this research could have significant implications for urban planners, transportation engineers, and policymakers. By integrating the PLOS into decision-making processes, cities can prioritize resources effectively, implement targeted safety improvements, and create pedestrian-friendly environments that encourage active transportation and enhance overall quality of life.

2 Data collection, extraction and methodology

The location of the study was chosen to be KIIT road, Bhubaneswar, India. This location was chosen for the study because of the high number of pedestrians ranging from students to faculty members and staff who must cross the major urban arterial to access various facilities. Further, Bhubaneswar is a smart tier-2 city, which represents majority of the cities of the country. The KIIT University is a major university [26] in the city, that is ranked within top 20 in India and ranked 147 in Asia [27] and does not have a boundary infrastructure. Rather, it has many satellite campuses across both sides of the major urban arterial road. The road is a 4-lane undivided road with bicycle lanes on both sides. Figure 1 represents the map location, with the camera locations for the study. Data was collected from 8:00 am to 7:00 pm. Data was collected with the help of two cameras, which were placed diagonally opposite (as shown in Figure 1) each at an angle to KIIT road to give a wide field of view. Figures 2a and 2b show the positions A and B at which the data was collected. The cameras are placed facing directions A and B. Various traffic parameters like vehicle counts and pedestrian speeds were then extracted using Kinovea video editing software to draw to the different findings. Counting of pedestrians was done manually. The methodology used for the study is shown in Figure 3.

3 Results and analysis

The results section of the study has been divided into subsection for easier and clear understanding.

3.1 Pedestrian dynamics

The present study deals with the safety aspects of pedestrians at unsignalized intersection. Therefore, firstly, the various traffic parameters related to pedestrian flow have been analysed. The number of pedestrians who were crossing KIIT road at the KIIT Times Square was determined by doing pedestrian counts. The pedestrian counts were done from 8:00 am to 7:00 pm on working days. The pedestrians who were walking on sidewalks were not counted since the study

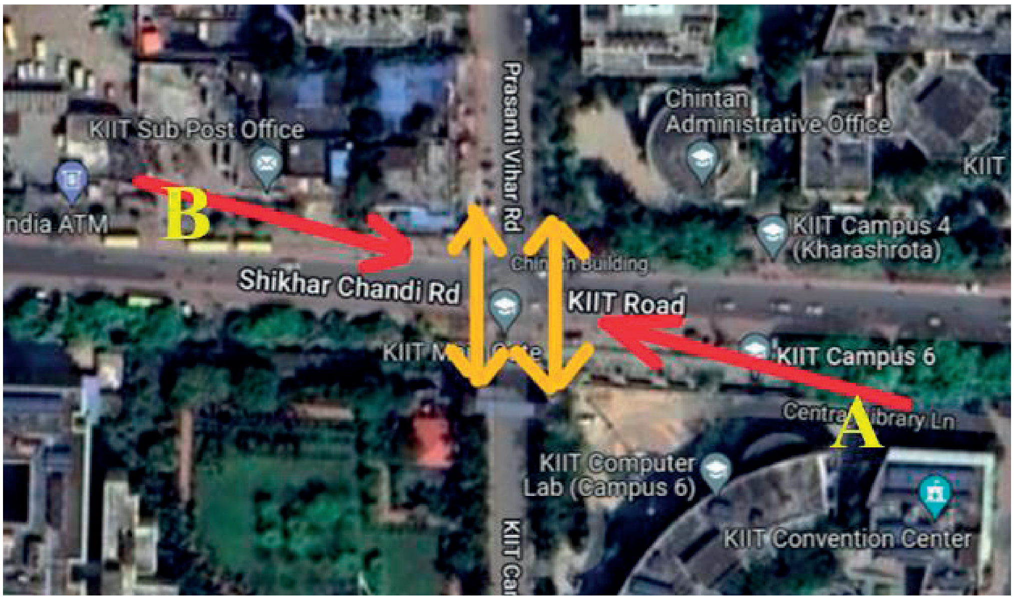
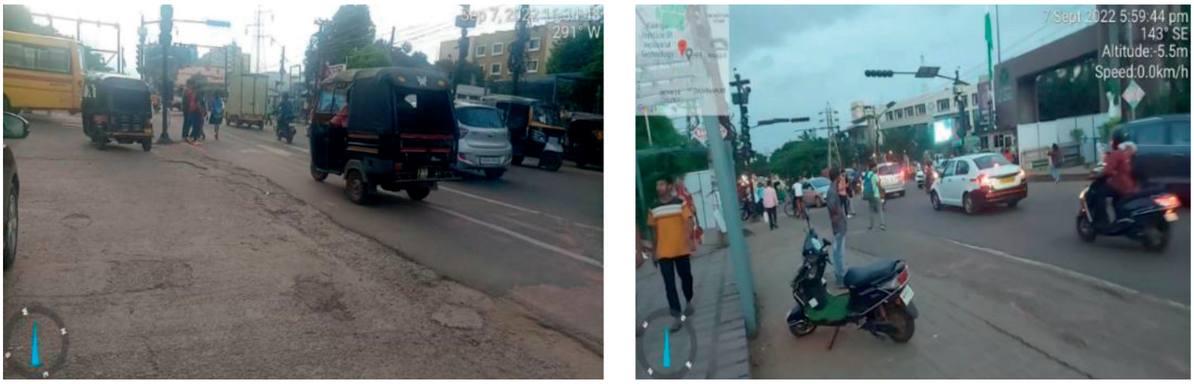


***Figure 1** Map view showing camera positions A and B*



(a) *(b)*

***Figure 2** Camera positions at A and B as shown in Figure 1*

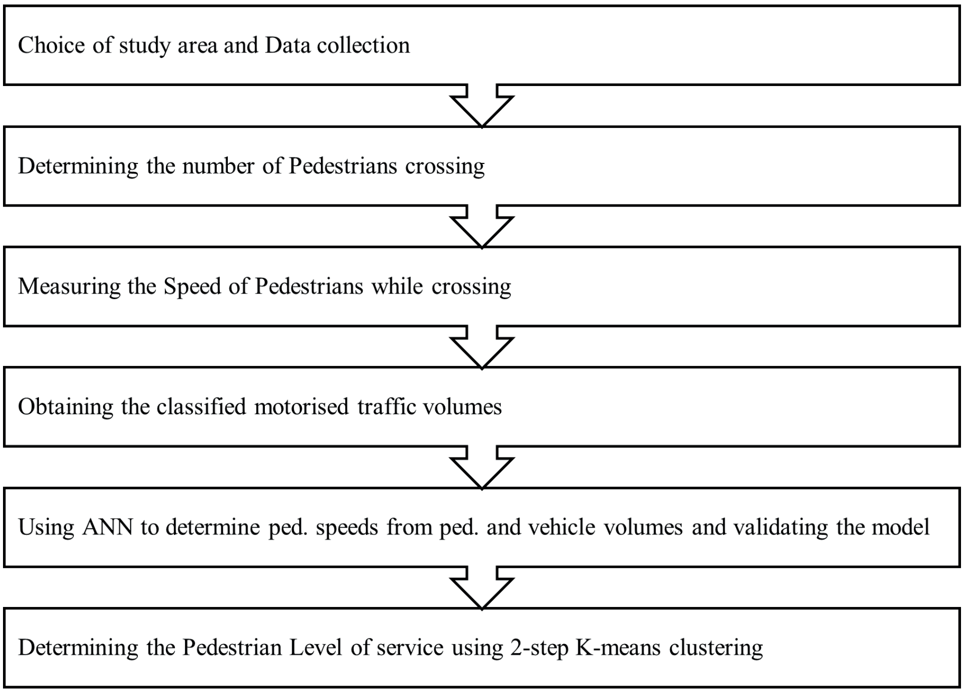


***Figure 3** Methodology for the study*

Table 1 Descriptive statistics of number of pedestrians crossing the road

	No. of Pedestrians Crossing per hour
Mean	753
Minimum	426
Maximum	1,188
Sum	8,280
Count Duration/day	11 hours

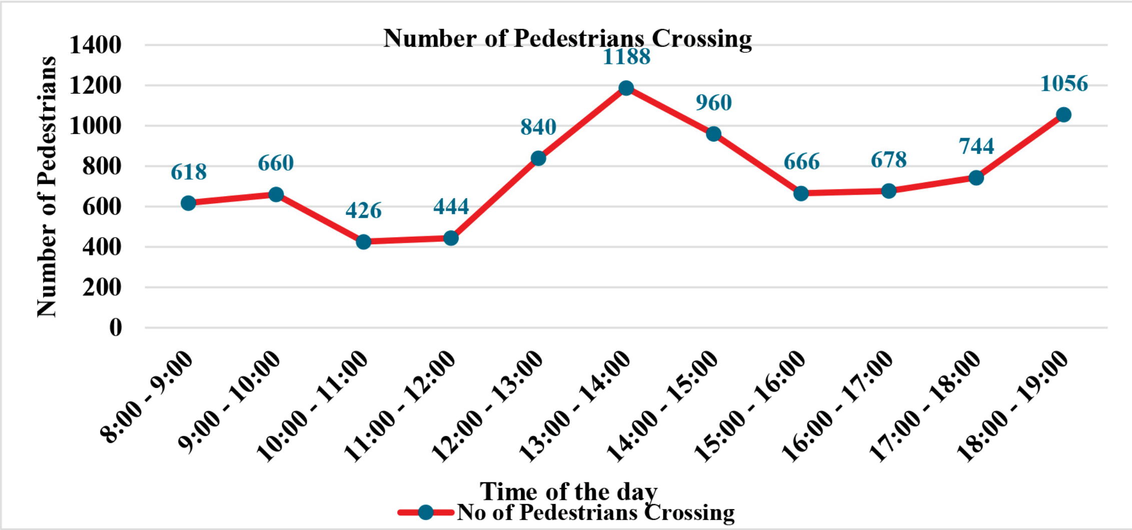


Figure 4 *Variation in average pedestrian volume over the day*

focuses on the behaviour of pedestrians crossing the main road either using or not using crosswalks. Table 1 showcases the descriptive statistics of pedestrians crossing the road per hour for a day.

The average total number of pedestrians crossing the KIIT Times Square was 8280 for the period of 11 hours in a single day. The average number of pedestrians crossing the road is 753 pedestrians per hour. The highest number of pedestrians crossing per hour recorded is 1188 and the lowest number is 426. The trend of the pedestrian flow is presented in Figure 4.

From Figure 4 can be noted that there are three peaks of pedestrian crossing the road of which first one is a low peak (9-10 AM) and next two are higher peaks (1-2 PM, and 6 -7 PM). The morning small peak is caused by the high number of students and university staff who are entering the university for morning classes and work. The second peak is observed at lunch time when the classes end for lunch break resulting in high number of pedestrians. The third peak is in the evening, which coincides with the closing of university and other offices nearby resulting in a peak period. The second peak at lunch time is the highest of the three peaks since most people get their lunch in the time window of 1 to 2 PM, while the start of classes/offices and leaving from work has a higher time window (like 8-10 AM and 5-7 PM). Next, a comparison was drawn between the individual and group crossing by pedestrians. Individual pedestrian crossing is when a single pedestrian moves from one end of the road to the other end of the road without anyone else moving with him/her at that same time. Group pedestrian crossing is when more than one person/ a group of people are moving from one end of the road to another end at the same time. In the present study, a group of pedestrians crossing the road is regarded as a single entity. This is because when people are crossing in a group, any vehicle - pedestrian crash would involve all of them. The number of group pedestrians crossing were counted for the different times of the day and the number of individuals in those groups was also noted as shown in Figure 5. It is observed that individual crossings are comparatively higher than the group crossings.

The highest number of group crossing is 204 groups (6:00 PM - 7:00 PM) and the lowest is 48 groups (8:00 AM-9:00 AM). In the morning, students are coming from their different residences and thus they cross the road individually. However, in the evening, students come from the university in groups and thus the higher number of group crossings is in the evening than in the morning.

Next, the speed of pedestrians crossing from direction A and direction B (as explained in "Data Collection and Extraction" section) was obtained from dividing the width of the road to the time taken by pedestrians to cross it. The average speed of pedestrians at different times of the day is shown in Table 2. Since, the difference between the group and individual

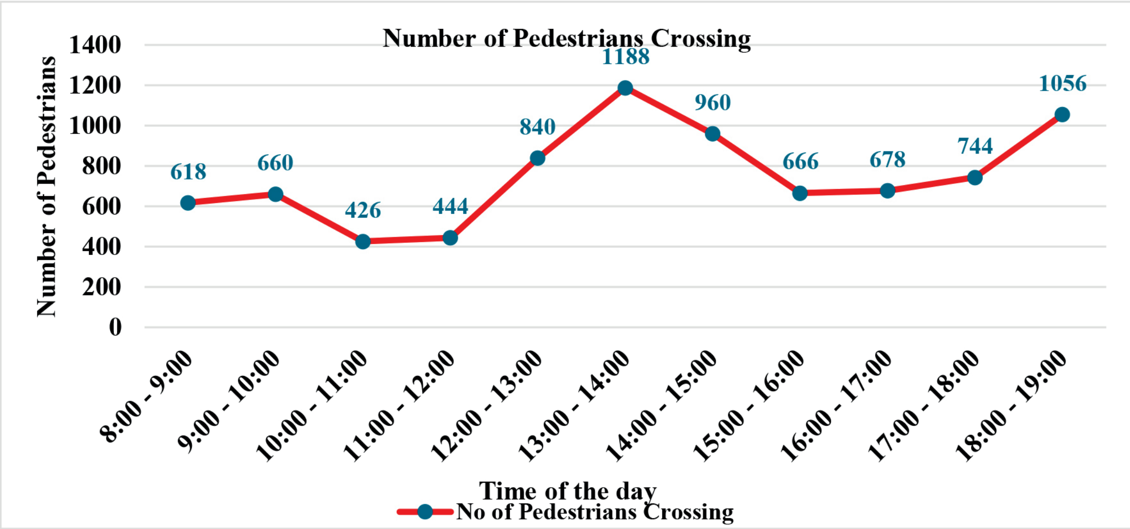


Figure 5 *Single and group pedestrian crossing the road*

Table 2 *Average speed of pedestrians while crossing the road*

Time of the Day	Average Speed at A (m/s)	Average Speed at B (m/s)
8-8.30 AM	0.86	1.09
8.30-9 AM	0.84	0.93
9-9.30 AM	0.87	1.18
9.30-10 AM	0.68	0.80
10-10.30 AM	1.03	1.28
10.30-11 AM	1.33	0.85
11-11.30 AM	0.91	1.22
11.30-12 PM	1.09	1.38
12-12.30 PM	1.29	1.13
12.30-1 PM	0.94	0.85
1-1.30 PM	0.90	0.93
1.30-2 PM	0.94	0.78
2-2.30 PM	1.04	1.02
2.30-3 PM	0.95	0.85
3-3.30 PM	0.93	0.93
3.30-4 PM	0.98	0.93
4-4.30 PM	0.86	1.02
4.30-5 PM	0.77	1.29
5-5.30 PM	0.83	1.11
5.30-6 PM	0.89	1.07
6-6.30 PM	1.24	1.04
6.30-7 PM	0.68	0.78

speeds of pedestrians are statistically insignificant, therefore all the obtained speeds have been considered for analysis. The variation trends of the speeds across the day is shown in Figure 6. The speeds are seen to vary during different times of the day with different peaks. For example, at position A, the speed of pedestrians are high between 10:30 AM -11:00 AM, 12:00 - 12:30 PM and 6:00 - 6:30 PM. At position B, high speed of pedestrians was observed in between 11:30 AM - 12:00 noon and 4:30 - 5:00 PM. According to [28], the average normal optimum crossing speeds of pedestrians is 1.2 m/s. The same optimum speed is also reported in IndoHCM [4] and few other studies. Considering this optimum speed, at maximum time intervals, from Figure 6 can be observed, that the speeds of pedestrians are less than optimum speed (below the red line), which shall lead to dissatisfaction among the pedestrians decreasing the PLOS for the facility. Speed has always been one of the

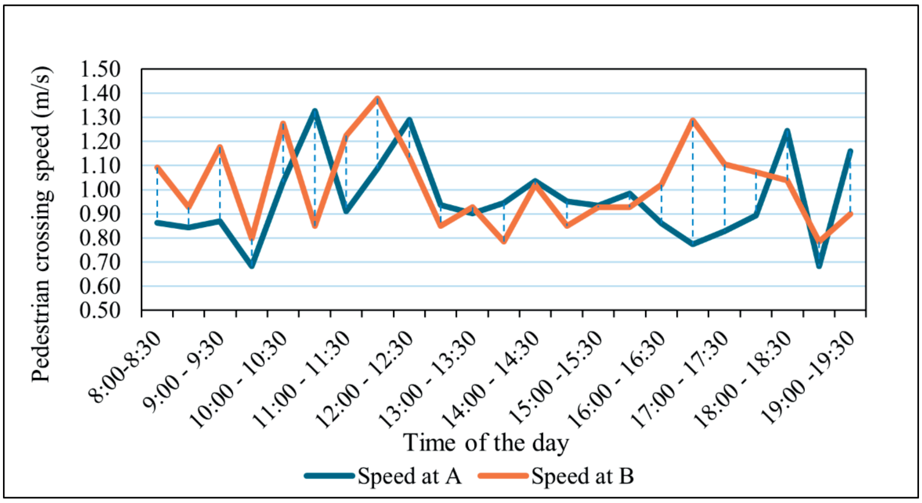


Figure 6 *Variation in average speeds of pedestrians while crossing the road*

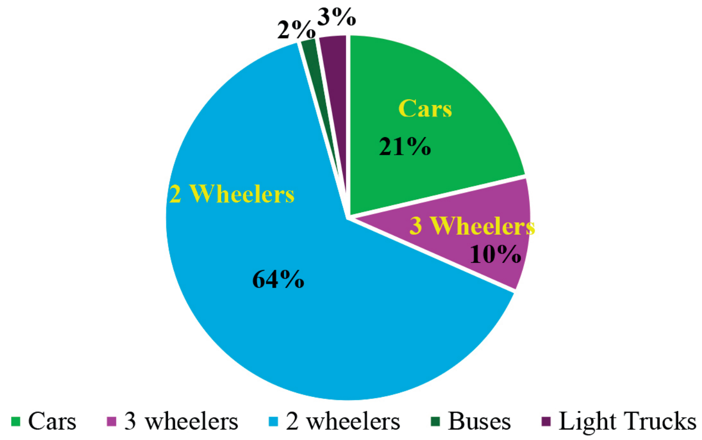


Figure 7 *Vehicular composition in Traffic stream*

most important parameters to be used for assessing various road user characteristics. However, speed is not the easiest parameter to measure. Volume is an easier parameter to measure than speed. Secondly, although it is commonly noticed from pedestrian flows and speeds that they are inversely related, but the vehicular dynamics needs to be assessed as it is common for pedestrians to be affected by vehicles, mainly when they are crossing the road. Therefore, in the next section of results and analysis, vehicular dynamics is evaluated and analysed to determine its effect on pedestrian speeds.

3.2 Vehicular dynamics

The studied road network is mainly used by 5 categories of vehicles, which include 2-wheelers, 3-wheelers, cars, light trucks, and buses. The percentage composition of these 5 categories is shown in Figure 7.

It can be observed from Figure 7, that 2-wheelers make up the highest percentage of composition of traffic with 64% share, followed by cars with 21%, 3-wheelers with 10%, light trucks with 3% and buses making up 2% of the traffic volume. It was observed that the vehicular volume affects the pedestrian crossing speeds along with the pedestrian volume. Secondly, the pedestrian crossing speeds can be used as one of the fundamental parameters for establishing the PLOS.

Therefore, pedestrian crossing speeds have been predicted in the present study using the volume of pedestrians crossing the road at a given point and the vehicular traffic volume using that same road at that said time. The PLOS is defined as the level of comfort provided to pedestrians as they are using different facilities on the road [4]. Although, the PLOS is calculated from the total delay faced by pedestrians in IndoHCM [4] guidelines, however, for crossing and jaywalking pedestrians it is difficult to assess the delay. Secondly, speed is the fundamental parameter, which leads to assessment of delay. Moreover, the delay ranges for PLOS would vary for different lane configurations. Therefore, indirectly, the speed with which the pedestrians are crossing the road is a simpler measure of their LOS. However, to calculate speeds, a definite section of road of known distance is required along with the time taken to cross the roadway. With heavy cross vehicular volumes and lower speeds of pedestrians, it becomes a tedious task to determine their speeds. Therefore, in the present study, Artificial Neural Network (ANN) has been utilized to determine the speeds of crossing pedestrians by considering their volume, and the vehicular volume on the road.

3.3 Pedestrian speed prediction using ANN

As mentioned earlier, in the present study, ANN has been used to predict pedestrian speeds while crossing the road. In the design of the system, the Pedestrian crossing volume and traffic volume have been used as the model parameters. Although, there are other numerous factors that affect the speed of pedestrians while crossing the roads, such as weather, age, gender, number of lanes, speeds of vehicles, etc., the purpose of this study was to find the easiest method that can be used to estimate pedestrian speeds and thus volumes of vehicles and pedestrians have been considered, which can be easily obtained on any road at any time. Secondly, the model used to predict the speeds of pedestrians while crossing the road gives highly accurate predicted results that are very close to the actual values with very small errors. In addition, this model predicted some pedestrian speeds with 100% accuracy. JMP Pro software made use of a variety of neural network validation approaches, including Holdback and K-fold methods. Holdback approach was found to offer improved prediction and validation for pedestrian crossing speeds. The ANN model was run with 1, 2, and 3 hidden layers, with the first two representing a shallow network and using TanH, Linear, and Gaussian activation functions, respectively. The three hidden layers employed in the model are shown in Figure 8. The method with the lowest Root Average Squared Error (RASE) has been selected for the prediction of the pedestrian crossing speeds.

Table 3 shows RASE of both the training and validation data for different ANN validation techniques and functions. The RASE for training shows how well the model fits the data used, while the RASE for validation shows how well the model would perform when given data it has not seen before. The lower the RASE, the more accurate the predictions will be. Thus, from Table 3, the activation function (Gaussian) and validation technique (Holdback) with a lower RASE (0.04) were used in ANN to model the data. 30% of the data was utilized for validation, while 70% was used for training. Figures 9a and 9b show the screenshots of ANN results graphs that when the pedestrian volume at A is 216 and the total vehicle volume is 1,639, the pedestrian crossing speed at A is predicted to be 0.88 m/s. Similarly, when the pedestrian volume at B is 276 and the total vehicle volume is 1,639, the pedestrian crossing speed at B is predicted to be 1.00 m/s. Table 4 presents the actual vs. predicted speeds of crossing pedestrians.

From Table 4 can be noted that the developed model gives very good results. With more training in ANN the model might give near 100% accuracies since even with first training of data sets, the results have been very precise. Table 5 shows the average, maximum and minimum errors between predicted and field values. It can be noted that the model generates an average

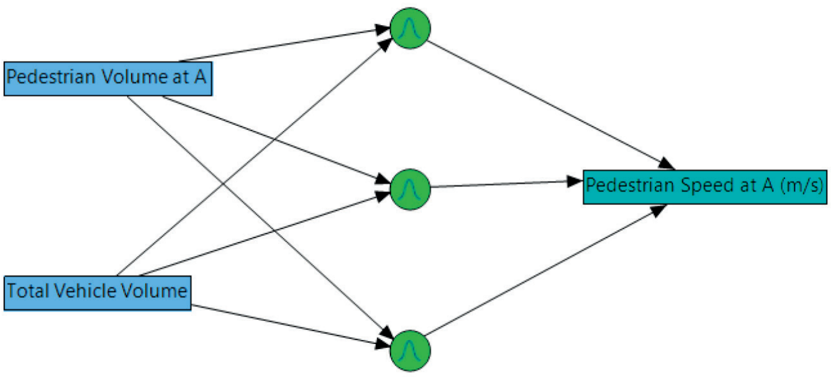
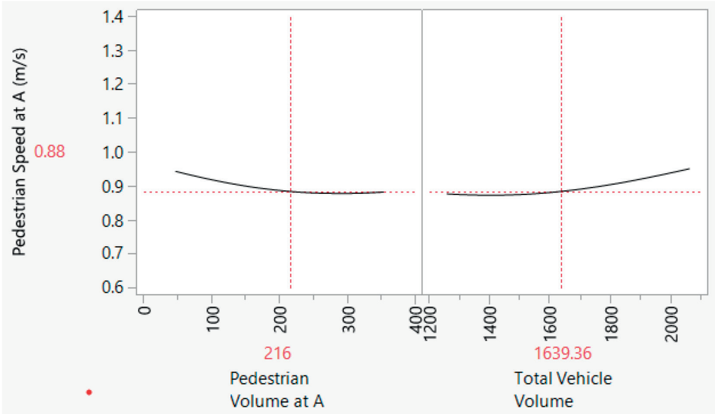


Figure 8 *Three hidden layers used for the model in ANN*

Table 3 *RASE for training and validation data*

Validation Technique	Activation function	Root Average Squared Error (Training data)	Root Average Squared Error (Validation data)
Holdback	TanH	0.19	0.08
	Linear	0.2	0.16
	Gaussian	0.2	0.04
K fold	TanH	0.11	0.19
	Linear	0.12	0.27
	Gaussian	0.06	0.15



(a)

(b)

Figure 9 *Screenshots of dynamic result graphs from ANN modelling*

Table 4 *Actual speeds of pedestrians while crossing the road and the Predicted pedestrian crossing speeds at both A and B*

Actual Pedestrian Speed at A (m/s)	Predicted Pedestrian Speed at A (m/s)	Actual Pedestrian Speed at B (m/s)	Predicted Pedestrian Speed at B (m/s)
0.86	0.88	1.09	1.01
0.84	0.87	0.93	1.04
0.87	0.94	1.18	1.00
0.68	0.91	0.80	1.02
1.03	0.90	1.28	1.04
1.33	0.94	0.85	1.03
0.91	0.92	1.22	1.04
1.09	0.90	1.38	1.04
1.29	0.92	1.10	1.04
0.94	0.96	0.88	1.04
0.90	0.94	0.91	1.03
0.94	0.90	0.77	0.81
1.04	0.92	1.00	1.03
0.95	0.89	0.87	1.03
0.93	0.87	0.96	0.96
0.98	0.91	0.93	1.01
0.86	0.88	1.06	0.96
0.77	0.91	1.29	1.04
0.83	0.88	1.11	1.02
0.89	0.88	1.07	1.02
1.24	0.87	1.04	0.96
0.68	0.89	0.79	1.03

Table 5 *Error in predicted vs field speeds at A and B*

Parameter	Error at A (m/s)	Error at B (m/s)
Average	0.12	0.14
Max	0.39	0.34
Min	0.01	0.00

error of 0.12 m/s at A and 0.14 m/s at B. It is noted that some of the speeds are predicted by the model with 100% accuracy as there is a minimum error of 0.00 m/s at B. The least error at A is 0.01 m/s. These results are very accurate, and this developed model can be used with confidence to predict pedestrian speeds by just utilising vehicular and pedestrian volumes. Next, these speeds have been utilised to perform clustering to develop a Pedestrian LOS based on their crossing speeds at unsignalized intersections. The delay ranges shall vary for different types of roads with different lane configuration, however speed ranges for PLOS will more or less remain the same at least for the surveyed city along with cities with similar demographic structure.

3.4 Development of PLOS using the pedestrian crossing speeds and clustering technique

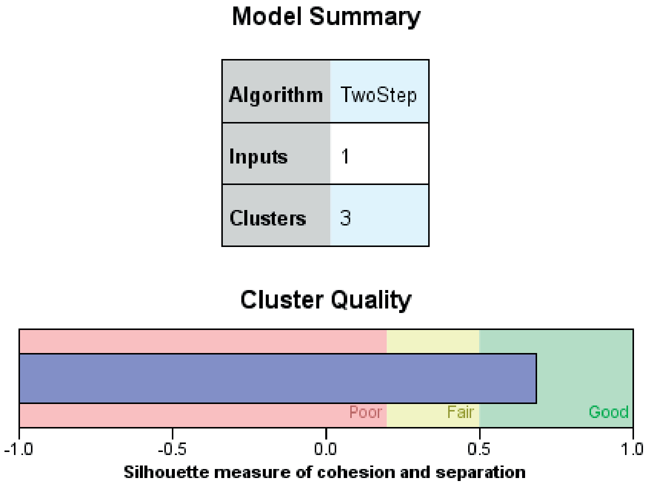
The speeds of pedestrians while crossing the road have been utilised to develop the Pedestrian LOS for the crossing behaviour. In the present study, it was possible to determine the Pedestrian level of service on the road without necessarily calculating the speed or delay. Only the volume counts of pedestrian and vehicles can help in assessing the LOS for a particular crossing point on road. Clustering technique aims to group the data in such a way that each group contains data points that are like one another and different from those found in other groups. K-means, K-medoid, and Hierarchical Agglomerative are the three popular methods of clustering to group/classify data points. The K-means clustering has been employed in this study to define the pedestrian speed ranges for different PLOS levels, since the K-means is an unsupervised classification method majorly effective for large data sets [29-31]. Further, past studies have shown that the k-means clustering should undeniably be utilised for data sets larger than 500. SPSS software was employed for performing clustering.

The K-mean method of clustering aims to form uniform clusters based on the diversity present within a cluster. Objects are thrown into different clusters at random to start the clustering process. Then, to reduce the within-cluster diversity, which is essentially the square of the distance between each item and the centre of its allocated cluster, they are gradually moved to other clusters with the help of repeated iterations. Since, 1.2 m/s has been established by various guidelines and researchers [4, 13, 32-33] as the average pedestrian speed in India, therefore, for urban areas, LOS C would start with pedestrian speeds of 1.2 m/s or higher. Therefore, in the present study, 2-step clustering is used; first for the speed data above 1.2 m/s and other for speed data less than 1.2 m/s. Before performing the cluster analysis, silhouette values are calculated to get the optimum number of clusters. Having silhouette value between 0.71 and 1.00 indicates the presence of strong clustering membership [29]. Figure 10 shows that the average silhouette value for speeds below and above the optimum average pedestrian crossing speed (1.2 m/s) is the highest for 3 number of clusters. Next the K-mean clustering is conducted by providing 3 number of clusters to be developed, each for speeds > 1.2 m/s and < 1.2 m/s. Additionally, the clustering is kept going until either convergence or a preset number of iterations are reached [34]. An essential component of the K-means clustering method is convergence. Simply put, when the cluster centers stop changing, the clusters have converged [35]. Multiple iterations are used to attain this convergence. For both groups (<1.2 m/s, >1.2 m/s), convergence have been attained after 3 and 2 iterations, respectively. Table 6 shows the change in clusters/iterations to achieve convergence and Table 7 presents the final cluster centers.

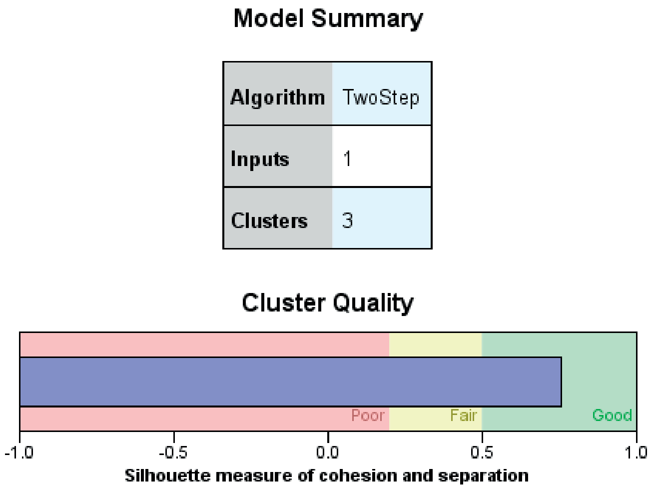
From Table 7, the ranges of PLOS are defined by considering the cluster centers of two consecutive clusters and then dividing the difference between them by 2. For example, for speed below 1.2 m/s, the cluster centers 1 and 2 are 0.67 and 0.94 m/s respectively. The difference between them is 0.94 - 0.67 = 0.27 m/s. If it is divided into 2 groups, the division comes at 0.67 + (0.27/2) = 0.81 m/s. Therefore, the range is < 0.81 m/s or 0-0.81 m/s. In similar ways, other ranges are also obtained. Thereafter, based on these values, the PLOS for crossing pedestrians is developed whose ranges are provided in Table 8. Any speeds above 1.2 m/s is considered good in terms of pedestrian service levels, whereas speeds below 1.03 m/s (less than LOS D) can be harmful for pedestrians considering they might be subjected to high level of discomfort and impatience leading to possible conflict scenarios.

4 Conclusion

Assessment of pedestrian safety is an important aspect at unsignalized intersections. In developing countries like India, most of the pedestrians are observed to jaywalk rather than using the designated cross



Silhouette plot for speeds below 1.2 m/s



Silhouette plot for speeds above 1.2 m/s
Figure 10 *Average silhouette values for 3 clusters of speeds below and above 1.2 m/s*

Table 6 *Convergence of cluster centers*

Convergence for speeds < 1.2 m/s			
	Change in Cluster Centers		
Iteration	1	2	3
1	0.210	0.114	0.022
2	0.032	0.003	0.032
3	0.000	0.000	0.000
Convergence for speeds > 1.2 m/s			
Iteration	Change in Cluster Centers		
	1	2	3
1	0.105	0.231	0.013
2	0.000	0.000	0.000

Table 7 *Cluster centers and ranges*

	Pedestrian Speed below 1.2 m/s			Pedestrian Speed above 1.2 m/s		
Number of clusters	1	2	3	4	5	6
Cluster centers	0.67	0.94	1.11	1.39	2.08	1.69
Cluster boundaries						
0	0.81	1.03	1.2	1.74	1.89	> 1.89
Number of clusters	1	2	3	4	5	6
Final Cluster ranges	0-0.81	< 0.81-1.03	< 1.03-1.2	< 1.2-1.74	< 1.74-1.89	> 1.89

***Table 8** PLOS ranges for crossing pedestrians*

Pedestrian Speed (m/s)	Pedestrian Level of Service
< 0.81	F
< 0.81 - 1.03	E
< 1.03 - 1.2	D
< 1.2 - 1.74	C
< 1.74 - 1.89	B
> 1.89	A

walks. At unsignalized intersections where no signals are provided for pedestrian crossing, development of a Pedestrian LOS is imperative as it can help assess the traffic scenario at the intersection from pedestrians' safety and comfort's point of view.

In the past many research and guidelines have established ranges of speeds, density, and delays at various pedestrian facilities for determination of PLOS. But there have been 2 major drawbacks. Firstly, the ranges developed by a guideline like HCM, 2000 does not hold true for other countries where the traffic conditions are different, and secondly, calculation of speeds and delays are not a straightforward calculation. In the present study, a new methodology along with introduction of ML and AI in form of ANN and clustering makes sure, the PLOS determination is not going to be a tedious work. Only volume counts of crossing pedestrians and moving vehicles can be used to assess the speed of pedestrian crossing and then the PLOS can be determined.

The present study has been conducted at a busy unsignalized intersection in the smart city of Bhubaneswar where both vehicular and pedestrian traffic is high. Considering that the area is a big university housing of more than 25000 students and 10000 staffs along with many IT hubs established in the vicinity, the traffic volume remains on the higher side. Firstly, the pedestrian dynamics were studied by observing their volume, trend of flow, and crossing speeds at different times of the day. Next, the classified vehicular volume on the main road throughout the day is also observed. It was observed that while the pedestrian flows showed a peak during lunch time (1-2 PM) along with two other regular morning and evening peaks, vehicular flow usually remained on the higher side, except for a few time intervals like 8-9 AM and 3-4 PM. The comparison of single and group of pedestrians crossing the road yielded similar results in terms of their speed. Thereafter, the vehicular and pedestrian volume were utilised as independent variables in ANN to determine the pedestrian crossing speeds. The results showed very accurate results with minimum and average errors of 0.00 m/s and 0.13 m/s respectively. These speeds were subjected to a 2-step clustering for developing the PLOS for the crossing manoeuvre at unsignalized intersection. Since, 1.2 m/s is observed to the average pedestrian crossing speed, not only from this study but in the past research, as well, therefore, speeds > 1.2 m/s were considered as LOS C, the design PLOS for crossing behaviour. Thereafter, speeds above 1.2 m/s and below 1.2 m/s were subjected to clustering and the ranges of PLOS from A to F were defined. It was observed that pedestrian speeds below 1.03 m/s might result in discomfort and inconvenience leading to forced crossing, which may cause conflict situations. The biggest advantage of this method to assess PLOS is that it does not consider the delays, which change based on the number of lanes on the road and the pedestrian speeds, which is directly obtained from the vehicular and pedestrian counts. The methodology used in this research can be adapted for cities globally to develop a standardized Pedestrian Level of Service (PLOS). The findings could have a significant value for urban planners, transportation engineers, and policymakers worldwide. By integrating the PLOS into planning and decision-making, cities can more effectively allocate resources, implement targeted safety measures, and create pedestrian-friendly environments that encourage active transportation and enhance the overall quality of urban life. Furthermore, various other factors, like pedestrian safety, can be incorporated into the present methodology to improve the designed PLOS levels.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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