

# LEVEL OF SERVICE ANALYSIS OF PEDESTRIAN CROSSING FACILITIES AT SIGNALIZED INTERSECTIONS UNDER HETEROGENEOUS TRAFFIC CONDITIONS

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*Received: January 24, 2023; Revised: May 24, 2023; Accepted: June 30, 2023*

## Abstract

While designing roadway facilities the pedestrian crosswalks must be given high importance, because these are the locations where pedestrians interact with vehicular traffic directly. This study aims to determine Pedestrian Perception values (PV) and assess the Level of Service (LOS) for crosswalk facilities provided for pedestrians at signalized intersections in heterogeneous traffic conditions. For this purpose, 24 crosswalks of six signalized intersections were chosen: 16 crosswalk locations were used for model development and eight crosswalk locations were used for model validation. The perception value of pedestrians was collected by conducting a questionnaire survey and traffic data was collected using a videographic survey. The parameters considered for the present study are: pedestrian volume, time is taken by the pedestrian to cross the crosswalk, length of crosswalk, pedestrian crossing speed, vehicular volume, and turning movements. The present research work proposed a mathematical model for Perception Value (PV) to assess the LOS of crosswalks of signalized intersections in urban areas. The results of the study are helpful in enhancing pedestrian safety and comfort at crosswalks.

**Keywords:** Crosswalks; Heterogeneous traffic; Level of Service; Pedestrians; Signalized intersections

## Introduction

Walking is the primary mode of transport for road users. In general, if any person is standing, running, or walking on the road or on the pavement is considered as a pedestrian. Signalized intersections are the most critical locations both for vehicular traffic as well as for pedestrians, because the

vehicles moving in different directions try to occupy the common space at the same point of time. Also, at identical times pedestrians require some time to pass. So, there may be a high chance of conflicts between vehicular traffic and pedestrians. The Indian traffic comprises of different vehicles with

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DOI: <https://doi.org/10.55766/sujst-2023-04-e0143>

Suranaree J. Sci. Technol. 30(4):010240(1-10)

different characteristics which try to use available space on the road without following any lane discipline. So, pedestrians lose their space under these traffic conditions. In India, most of the intersections are lack of pedestrian facilities and proper planning.

Pedestrians are one of the major commuters on Indian urban streets. In India basically, pedestrian facilities are neglected in transportation planning and management. The WHO (World Health Organization) (WHO 2018) identified road accidents as the biggest killers in the first global status report. The report revealed that the countries with the middle-income levels contribute 90% of deaths arising because of road fatalities. Pedestrian collisions should not be accepted as inevitable because they are both predictable and preventable. It is sad to observe that India is identified as a worldwide leader in road accidents witnessing the tremors of road fatalities and injuries. Hence it is necessary for organizations coming from various sectors to join hands in developing a proper road safety management structure for evolving a safe environment. So better facilities need to be provided for pedestrians as their number is increasing day by day. There is no true representative for Indian conditions as the models developed for urban conditions in Western countries are different from Indian conditions. Therefore, studies on pedestrians need to be done to provide better facilities to pedestrians in India.

The quality of pedestrian facilities provided at signalized intersections can be assessed through pedestrian Level of Service (LOS). The pedestrian level-of-service concept was first introduced in the Highway Capacity Manual (HCM) in 1985. PLOS is a qualitative measure used to relate the quality of service at pedestrian facilities and it represents in terms of perceived value, convenience, and comfort.

Muraleethran *et al.* (2005) assessed the factors influencing the level of service of pedestrian crossing at signalized intersections and those factors are space at corners, crossing facilities, pedestrian-vehicle interactions, and delay. Bian *et al.* (2009) developed a pedestrian LOS model considering the (i) pedestrian delay (ii) crossing facilities (iii) traffic conflicts for assessing the pedestrian level of service at a signalized intersection. Kadali and Vedagiri (2013) assessed factors affecting the level of service such as conflicting traffic, pedestrian flow, and pedestrian delay. Sahani *et al.* (2017) developed a pedestrian LOS model for crosswalks at signalized intersections based on pedestrian-vehicular interaction time and total delay.

The comfort and safety criteria of pedestrians is not considered in the previous research. The aim of the present study is to analyze the pedestrian

crossing behavior at the approach of a signalized junction and to develop a model for predicting the level of service of pedestrian crossing at a signalized junction approach. For this purpose, the present study assesses the LOS of each selected crosswalk facility, and the results are helpful in enhancing pedestrian safety. The perceived value is evaluated based on the factors related to pedestrian comfort and safety at the crosswalks.

## Literature Review

A comprehensive literature of earlier studies has been collected. The several earlier studies on the Level of Service assessment of pedestrian facilities are presented in this section. LOS for crosswalks was defined (Muraleethran *et al.* 2005) at urban intersections in Japan. Questionnaire survey was conducted to obtain perceived values by pedestrians and multi-stage regression analysis was done to estimate LOS in this study. The corner space, crossing facilities, delay, and pedestrian-bicycle interactions were the factors considered to assess LOS. The pedestrian LOS was developed based on pedestrian delay and pedestrian-bicycle interactions. A LOS model was proposed (Petritsch *et al.* 2006) for pedestrian crossings in Florida. The model incorporated perceived pedestrian comfort and safety. The study results showed that the developed model was reliable to access LOS of pedestrians for metropolitan cities in Florida.

A model was proposed (Yang *et al.* 2006) to predict the pedestrian behavior at street crossings considering the effect of policemen and other road users. The model represented the behavior of two categories of pedestrians: opportunistic pedestrians and relations obeying pedestrians. The results of the simulation represented the violation behavior of pedestrians. A pedestrian LOS model was developed (Bian *et al.* 2009) at signalized intersections in China considering pedestrian delay and traffic conflicts. The LOS was assessed based on a questionnaire survey i.e., the real response of the pedestrian. LOS model was developed using linear regression models. A comprehensive study was conducted (Ren *et al.* 2011) on pedestrian crossing behavior at signalized intersections. The study results revealed that, the middle-aged people and women are violating traffic rules. Various models and methods were (Singh *et al.* 2011) considered for defining LOS for pedestrians and a consolidated model was developed to fit for universal application. Several factors (Jensen, 2013) affecting bicycle and pedestrian LOS were found at crossings of roundabouts. The study found that the traffic volume, crossing length and roundabout size affects LOS of bicycles and pedestrians.

A model for pedestrian LOS in the urban environment of Greek city was proposed (Paraskevi and Pitsiava, 2012). The study assessed all the methodologies available to define pedestrian LOS and found the suitability and weaknesses of each proposed model. A pedestrian delay mathematical model was proposed (Li and Xiaofa, 2013) using multiple linear regression analysis. The factors considered in this study were car volume, pedestrian volume, and speed. The model showed good prediction of pedestrian LOS model. A LOS model for pedestrians at midblock crossing facilities was proposed (Zhao *et al.* 2014) in China. The study results showed that motor vehicle volume, distance between marked and unmarked crosswalks were the factors which most influenced the LOS. The study results were helpful in setting out the desirable distance between marked and unmarked crosswalks. A study was conducted (Onelcin and Alver, 2017) on safety margin and crossing speeds of pedestrians. The videographic survey was conducted to investigate crossing speeds of pedestrians and perceptions. The age, group size, luggage carrying and gender were the factors found to affect crossing speed. The quantitative and qualitative factors were considered (Sahani *et al.* 2017) for defining pedestrian LOS. Both non-motorized and motorized were considered to develop LOS model using ANN clustering. The results showed that, 75% of crosswalks offered average service levels and 4% of crosswalks offered very poor service levels.

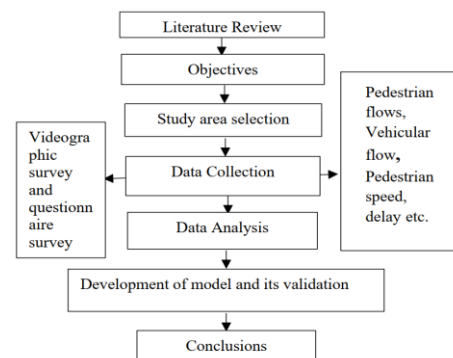
A LOS model was proposed (Thota *et al.* 2018) for pedestrians at junction crosswalks based on pedestrian delay and perception value. The data was collected using a videographic survey as well as a questionnaire survey. The study results showed that the pedestrian-vehicle interactions were causing crashes and affecting the LOS of pedestrians. LOS for pedestrian crosswalks was evaluated (Indumathy *et al.* 2020) at unsignalized intersections based on pedestrian perception from the point of view of comfort and safety. The traffic data as well as pedestrian perceptions were collected using both videographic and questionnaire survey at Ernakulam, Kerala. The stepwise regression LOS model was developed for assessing LOS of unsignalized intersections. LOS for pedestrian crosswalks (Ahmed *et al.* 2021) was evaluated in urban areas in Malaysia. The study considered several indicators to assess the quality level of crosswalks. Among those, the zebra crossing provision was identified as the most important indicator and the drainage provision near the crosswalks was identified as the least important indicator. A questionnaire survey was conducted for pedestrians to assess the scores.

From the previous research work it can be concluded that most of the studies were done in foreign countries where lane disciplined traffic prevails. Only few studies were done in India in mixed traffic conditions. From the past accident statistical analysis given by WHO, it was found that India stands top in occurrence of accidents in the world which were mainly due to lack of proper pedestrian facilities and improper usage of provided pedestrian facilities by encroaching vehicular traffic. Therefore, it is very much needed to conduct this study in India. Also, previous researchers developed pedestrian LOS models based on factors: gap perception, crossing speed, traffic volume, age, and gender. But it is observed in India that the crossing time and turning movements are affecting pedestrian LOS. In addition to these factors, present study considers crossing time, turning movements effect on crosswalks, pedestrian safety and comfort at urban signalized intersections in heterogeneous traffic conditions.

## Study Methodology

The following flow chart in Figure 1 shows the general methodology for analyzing the LOS for crosswalks at signalized intersections.

In the first stage of methodology, in order to identify the objectives many literatures regarding pedestrian studies were collected and critically reviewed the most related ones. Based on the review of literature, objectives were fixed for the present study. After fixation of objectives, study area was identified: six signalized intersections were selected. In the process of data collection questionnaire survey was done at the intersections also, the site parameters were taken. Videographic survey was also done to collect the required traffic flow data. Later, Pearson correlation and regression



**Figure 1. Flow chart showing the methodology of the study**

analysis were done. Correlation was done to correlate the dependent and independent variables and regression analysis was done in SPSS to develop the model. The intersection was developed using three signalized intersection data and validated on the fourth signalized intersection data.

## Study Area

Six signalized intersections of 24 crosswalks were selected for the present study from three cities: Warangal, Kerala, and Hyderabad, wherein 4 intersections (16 crosswalks) data were used for model calibration and 2 intersections (8 crosswalks) data were used for model validation. The intersections are selected based on criteria that there

exists pedestrian-vehicle interactions, when green time is given to vehicular movement, which is an unsafety condition for pedestrians. Kazipet (I-1) and KU (I-2) intersections were selected from Warangal city. Gandimaisamma (I-3), Suchitra (I-4), and Paradise (I-5) intersections were selected from Hyderabad city. Eranhipalam (I-6) intersection was selected from Kerala city. Figure 2 shows a pedestrian-vehicle interactive situation for KU intersection. The Google images of the study intersections are shown in Figures 3-8.

All the selected intersections from I-1 to I-6 are four-legged intersections with permitted through, right, and left turn movements.

## Field Data Collection

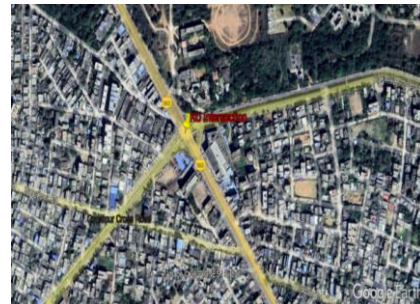
After the site investigation, the field data for the present study was collected from study intersections. The data collected from the field are the length of a crosswalk, provision of turn lanes, and Signal details such as green time and cycle time. The site observations were done to find the actual conditions in the site, like crosswalk length, approach width, traffic conditions, and pedestrian facilities. The data was collected by various methods such as video recording and manual observations by conducting questionnaires. The cycle time (s), green time (s), and crosswalk length (m) for each study approach are given in Table 1.



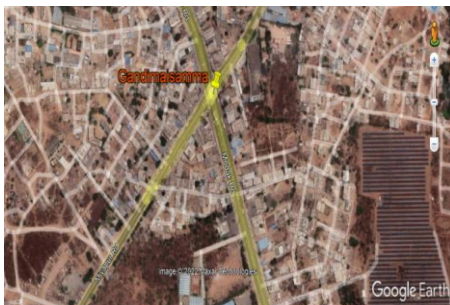
**Figure 2. Pedestrian-vehicle interactions at KU intersection**



**Figure 3. Kazipet Intersection (I-1)**



**Figure 4. KU Intersection (I-2)**



**Figure 5. Gandimaisamma Intersection (I-3)**



**Figure 6. Suchitra Intersection (I-4)**



Figure 7. Paradise Intersection (I-5)

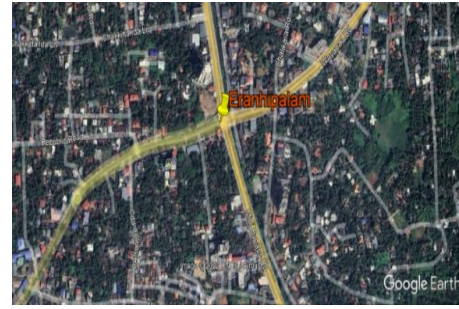


Figure 8. Eranhilalam Intersection (I-6)

Table 1. Signal timings and crosswalk length details of study approaches

| Intersection | Approach | Cycle time (s) | Green time (s) | Crosswalk length (m) |
|--------------|----------|----------------|----------------|----------------------|
| I-1          | NB-1     | 140            | 35             | 16.4                 |
|              | SB-1     |                | 35             | 19.7                 |
|              | EB-1     |                | 30             | 18                   |
|              | WB-1     |                | 20             | 12.9                 |
| I-2          | NB-2     | 130            | 27             | 16.2                 |
|              | SB-2     |                | 27             | 16.5                 |
|              | EB-2     |                | 32             | 20.9                 |
|              | WB-2     |                | 32             | 19.9                 |
| I-3          | NB-3     | 150            | 45             | 29.2                 |
|              | SB-3     |                | 25             | 12                   |
|              | EB-3     |                | 30             | 20                   |
|              | WB-3     |                | 35             | 28                   |
| I-4          | NB-4     | 180            | 60             | 23.6                 |
|              | SB-4     |                | 50             | 24.7                 |
|              | EB-4     |                | 30             | 38.4                 |
|              | WB-4     |                | 30             | 22.3                 |
| I-5          | NB-5     | 110            | 25             | 18.3                 |
|              | SB-5     |                | 25             | 19.8                 |
|              | EB-5     |                | 25             | 13.9                 |
|              | WB-5     |                | 25             | 15                   |
| I-6          | NB-6     | 180            | 46             | 23.6                 |
|              | SB-6     |                | 44             | 24.7                 |
|              | EB-6     |                | 38             | 18.1                 |
|              | WB-6     |                | 44             | 21.4                 |

Table 2. Pedestrian delay values

| Intersection | Approach | Pedestrian delay (s) |
|--------------|----------|----------------------|
| I-1          | NB-1     | 19.69                |
|              | SB-1     | 19.69                |
|              | EB-1     | 21.61                |
|              | WB-1     | 25.71                |
| I-2          | NB-2     | 20.4                 |
|              | SB-2     | 20.4                 |
|              | EB-2     | 18.47                |
|              | WB-2     | 18.47                |
| I-3          | NB-3     | 18.38                |
|              | SB-3     | 26.04                |
|              | EB-3     | 24                   |
|              | WB-3     | 22.04                |
| I-4          | NB-4     | 20                   |
|              | SB-4     | 23.47                |
|              | EB-4     | 31.25                |
|              | WB-4     | 31.25                |
| I-5          | NB-5     | 16.42                |
|              | SB-5     | 16.42                |
|              | EB-5     | 16.42                |
|              | WB-5     | 16.42                |
| I-6          | NB-6     | 24.94                |
|              | SB-6     | 25.69                |
|              | EB-6     | 28.01                |
|              | WB-6     | 25.69                |

A minimum green time of 25 seconds and a maximum green time of 60 seconds is observed for the study intersections. The minimum and maximum crosswalk length observed for the study approaches are 12 m and 38.4 m respectively. Also, the pedestrian crossing delay is calculated by using the relation given in the Highway Capacity Manual (HCM) (2010) which is shown in equation 1.

$$pedestrian\_crossing\_delay = 0.5 \times \frac{C - g}{2C} \quad (1)$$

Where, C is Cycle time in seconds and g is green time in seconds.

The pedestrian crossing delay was calculated using field observed values and are given in the Table 2.

### Questionnaire Survey

The questionnaire survey is done at all the study intersections. The pedestrians crossing the study intersection are interviewed to assess the user perception towards their convenience and safety. In this survey, the interviewer will ask questions to pedestrians who cross the crosswalk at the approach by standing at one corner of the crosswalk to get the pedestrian perception value (PPV). The pedestrians were interviewed about various demographic characteristics such as gender, age, frequency of crossing the intersection, luggage carrying, i.e., heavy, or light, the purpose of crossing the crosswalk and their perception rating. Pedestrians were given a rating which is ranging from 1 to 6 which indicates very good to worst respectively. The pedestrian perception value obtained from the analysis of this questionnaire survey is considered as the dependent variable and a model is developed for this pedestrian perception value, which defines Level of Service of pedestrians crossing the signalized junctions under heterogeneous traffic conditions. The questionnaire survey sheet used in this study is shown in Table 3.

Based on the rating given by the pedestrians, the perception value has been calculated. The random sampling method is used, and the number of pedestrians responded is shown in Table 4.

**Table 3. Questionnaire survey sheet**

| Questionnaire Survey                                                                  |                |
|---------------------------------------------------------------------------------------|----------------|
| Survey Site:                                                                          | Response time: |
| Age:                                                                                  | Gender:        |
| Luggage:                                                                              |                |
| A. Heavy                                                                              |                |
| B. Normal                                                                             |                |
| C. Light                                                                              |                |
| D. No luggage                                                                         |                |
| Is walking one of your main travel mode?: Yes/No                                      |                |
| How often do you usually use the crosswalk?                                           |                |
| A. First time                                                                         |                |
| B. A few times a week                                                                 |                |
| C. Every day                                                                          |                |
| D. More than once a day                                                               |                |
| E. Few times a month.                                                                 |                |
| How much comfortable do you feel while crossing this road?                            |                |
| Rate the crosswalk?                                                                   |                |
| A. Very good                                                                          |                |
| B. Good                                                                               |                |
| C. Average                                                                            |                |
| D. Inferior                                                                           |                |
| E. Poor                                                                               |                |
| F. Worst                                                                              |                |
| What is the purpose of using this crosswalk?                                          |                |
| A. Work                                                                               |                |
| B. Shopping                                                                           |                |
| C. Others                                                                             |                |
| Do you feel safe while crossing the crosswalk? Rate the crosswalk in terms of safety. |                |
| A. Very good                                                                          |                |
| B. Good                                                                               |                |
| C. Average                                                                            |                |
| D. Inferior                                                                           |                |
| E. Poor                                                                               |                |
| F. Worst                                                                              |                |

**Table 4. Questionnaire survey sheet**

| Approach | Pedestrians responded | Perception value |
|----------|-----------------------|------------------|
| NB-1     | 70                    | 2.1              |
| SB-1     | 61                    | 3.3              |
| EB-1     | 64                    | 2.6              |
| WB-1     | 59                    | 2.5              |
| NB-2     | 67                    | 2.6              |
| SB-2     | 71                    | 2.9              |
| EB-2     | 61                    | 2.3              |
| WB-2     | 59                    | 1.5              |
| NB-3     | 58                    | 3.5              |
| SB-3     | 59                    | 2.9              |
| EB-3     | 66                    | 3.3              |
| WB-3     | 65                    | 3.2              |
| NB-4     | 67                    | 3.5              |
| SB-4     | 62                    | 3.6              |
| EB-4     | 57                    | 3.1              |
| WB-4     | 59                    | 2.9              |
| NB-5     | 63                    | 3.4              |
| SB-5     | 67                    | 3.5              |
| EB-5     | 65                    | 2.6              |
| WB-5     | 69                    | 2.8              |
| NB-6     | 70                    | 2.4              |
| SB-6     | 57                    | 2.5              |
| EB-6     | 69                    | 3.2              |
| WB-6     | 64                    | 3.4              |

The pedestrian perception values shown in Table 4 are the average rating values given by the pedestrians in terms of comfort and safety only i.e., Very good (1) to Worst (6).

### Videographics Survey

Video recording was done twice in a day: in the morning from 8 to 11 and in the evening from 4 to 7. Two video cameras were set up near the intersection in such a way that all the four crosswalks are covered. The data such as pedestrian speed during crossing, pedestrian volume and turning vehicle count was extracted from the recorded videos. The pedestrian speed, turning volumes and pedestrian flow are tabulated in Table 5.

As per IRC (1985) the walking speed of pedestrians in general is 1.2m/s. But it is observed that the crossing speeds of pedestrians at most of the study locations is quite more than the normal walking speed of pedestrians. From the field data it is also observed that the maximum pedestrian flow observed is 33 pedestrians per hour.

### Model Development

The regression analysis was done using Statistical Package for Social Sciences (SPSS) software. The Intersections I-1, I-2, I-3 and I-4 are used for the development of the model, whereas I-5 and I-6 are used for model validation. The parameters considered for the modeling are Pedestrian volume, pedestrian crossing time, length of crosswalk, pedestrian crossing speed, vehicle volume, and turning movements. Table 6 shows the correlation coefficients of the considered variables.

Where, PV is the pedestrian perception value, ped vol is the pedestrian volume, CT is the crossing time, CL is the cross length, CS is the pedestrian crossing speed, TH is through vehicle volume, RT is right turning vehicle volume and LT is left turning vehicle volume.

From the correlation matrix it is observed that the right-turning vehicle volume and the left-turning vehicle volume are only having a significant correlation with perception value (PV). So, right-turning vehicle volume and left-turning vehicle volume are only considered for regression analysis. The results of the regression analysis are presented in Table 7.

The statistical t-value is greater than 1.96 and the p-value is less than 0.05. Therefore, the model is developed based on right-turning vehicle volume and left-turning vehicle volume and is shown in Equation 2.

$$PV = 2.35 - 0.00087RT + 0.001315LT \quad (2)$$

$$(R^2=0.876)$$

PV is the perception value of the pedestrian; RT is the right-turning vehicle volume (veh/hr) and LT is the left-turning vehicle volume (veh/hr). The model developed satisfies the statistical p-value and t-value limits. Though the model developed incorporated the left turn and right turn vehicular volumes, the other factors like pedestrian vol, pedestrian crossing time, crossing length, and crossing speed also have an impact on PV but of less significance. The Perception value obtained

from the developed model can be used for defining the pedestrian crosswalk level of service (LOS). If the PV value is less the LOS will be better. The proposed LOS for pedestrian crosswalks at signalized intersection approaches is judged based on perception value criteria which is given in Table 8. The Level of Service -A represents an excellent crosswalk performance while Level of Service F represents a very poor crosswalk.

Level of Service A, B, C, D, E, and F represents excellent performance, good performance, average performance, poor performance, abysmal performance, and worst performance respectively.

**Table 5. The pedestrian speed, turning volumes and pedestrian flow at study crosswalks**

| Approach | Through volume (veh/h) | Right turn volume (veh/h) | Left turn volume (veh/h) | 15 <sup>th</sup> percentile speed (m/s) | 50 <sup>th</sup> percentile speed (m/s) | 85 <sup>th</sup> percentile speed (m/s) | 98 <sup>th</sup> percentile speed (m/s) | Pedestrian flow (ped/h) |
|----------|------------------------|---------------------------|--------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-------------------------|
| NB-1     | 1699                   | 87                        | 112                      | 0.95                                    | 1.03                                    | 1.22                                    | 1.42                                    | 16                      |
| SB-1     | 840                    | 513                       | 1097                     | 1.11                                    | 1.26                                    | 1.29                                    | 1.44                                    | 24                      |
| EB-1     | 92                     | 151                       | 224                      | 0.65                                    | 0.73                                    | 0.82                                    | 0.95                                    | 14                      |
| WB-1     | 220                    | 124                       | 196                      | 1.42                                    | 1.51                                    | 1.62                                    | 1.75                                    | 19                      |
| NB-2     | 506                    | 153                       | 234                      | 0.78                                    | 0.84                                    | 0.91                                    | 0.99                                    | 22                      |
| SB-2     | 118                    | 201                       | 354                      | 0.82                                    | 0.94                                    | 1.04                                    | 1.12                                    | 18                      |
| EB-2     | 830                    | 98                        | 122                      | 1.02                                    | 1.14                                    | 1.21                                    | 1.3                                     | 16                      |
| WB-2     | 1083                   | 65                        | 102                      | 1.19                                    | 1.38                                    | 1.41                                    | 1.57                                    | 9                       |
| NB-3     | 321                    | 975                       | 1564                     | 1.34                                    | 1.52                                    | 1.68                                    | 1.72                                    | 25                      |
| SB-3     | 1387                   | 224                       | 349                      | 0.64                                    | 0.78                                    | 0.82                                    | 0.91                                    | 17                      |
| EB-3     | 243                    | 498                       | 1109                     | 0.93                                    | 1.16                                    | 1.47                                    | 1.62                                    | 31                      |
| WB-3     | 131                    | 365                       | 854                      | 1.56                                    | 1.67                                    | 1.78                                    | 1.85                                    | 28                      |
| NB-4     | 962                    | 996                       | 1598                     | 0.68                                    | 0.74                                    | 0.86                                    | 0.96                                    | 24                      |
| SB-4     | 595                    | 1004                      | 1607                     | 0.91                                    | 1.02                                    | 1.23                                    | 1.34                                    | 13                      |
| EB-4     | 52                     | 256                       | 442                      | 1.12                                    | 1.19                                    | 1.25                                    | 1.32                                    | 22                      |
| WB-4     | 898                    | 200                       | 302                      | 0.78                                    | 0.82                                    | 0.91                                    | 1.03                                    | 27                      |
| NB-5     | 189                    | 597                       | 1212                     | 0.93                                    | 1.05                                    | 1.18                                    | 1.24                                    | 15                      |
| SB-5     | 288                    | 965                       | 1556                     | 1.65                                    | 1.73                                    | 1.82                                    | 1.91                                    | 19                      |
| EB-5     | 553                    | 168                       | 265                      | 1.32                                    | 1.44                                    | 1.57                                    | 1.64                                    | 23                      |
| WB-5     | 853                    | 197                       | 297                      | 1.42                                    | 1.57                                    | 1.68                                    | 1.82                                    | 20                      |
| NB-6     | 1294                   | 108                       | 145                      | 1.65                                    | 1.72                                    | 1.84                                    | 1.98                                    | 13                      |
| SB-6     | 1104                   | 135                       | 197                      | 1.62                                    | 1.82                                    | 1.91                                    | 1.98                                    | 33                      |
| EB-6     | 742                    | 371                       | 843                      | 0.83                                    | 0.92                                    | 1.22                                    | 1.31                                    | 26                      |
| WB-6     | 138                    | 657                       | 1242                     | 0.95                                    | 1.03                                    | 1.22                                    | 1.42                                    | 21                      |

**Table 6. Correlation matrix of the variables considered for modelling**

|         | PV     | Ped vol | CT     | CL     | CS    | TH    | RT    | LT |
|---------|--------|---------|--------|--------|-------|-------|-------|----|
| PV      | 1      |         |        |        |       |       |       |    |
| Ped vol | 0.312  | 1       |        |        |       |       |       |    |
| CT      | -0.345 | 0.110   | 1      |        |       |       |       |    |
| CL      | 0.215  | 0.023   | 0.121  | 1      |       |       |       |    |
| CS      | 0.302  | 0.201   | -0.135 | 0.251  | 1     |       |       |    |
| TH      | -0.381 | 0.013   | 0.006  | -0.142 | 0.206 | 1     |       |    |
| RT      | 0.827  | 0.192   | 0.211  | 0.004  | 0.174 | 0.124 | 1     |    |
| LT      | 0.869  | 0.254   | 0.015  | 0.100  | 2.331 | 0.323 | 0.216 | 1  |

**Table 7. Regression analysis results**

| Labels    | Coefficients | Standard error | t-value |
|-----------|--------------|----------------|---------|
| Intercept | 2.35000      | 0.08592        | 27.34   |
| RT        | -0.00087     | 0.00083        | -3.45   |
| LT        | 0.001315     | 0.00047        | 2.74    |

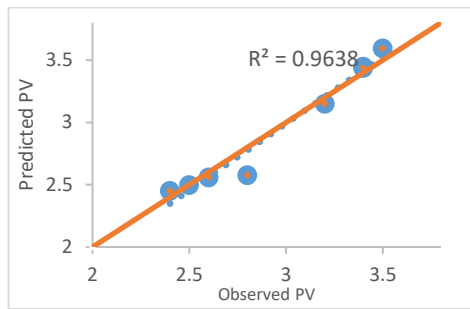


Figure 9. Validation chart

Table 8. Proposed LOS for pedestrian crosswalks at signalised intersections

| Level of Service | Perception Value |
|------------------|------------------|
| A                | $\leq 2$         |
| B                | 2-3              |
| C                | 3-4              |
| D                | 4-5              |
| E                | 5-6              |
| F                | $\geq 6$         |

Table 9. Defining Level of Service for the selected crosswalks

| Approach | PV  | LOS | Approach | PV  | LOS |
|----------|-----|-----|----------|-----|-----|
| NB-1     | 2.1 | B   | NB-4     | 3.5 | C   |
| SB-1     | 3.3 | C   | SB-4     | 3.6 | C   |
| EB-1     | 2.6 | B   | EB-4     | 3.1 | C   |
| WB-1     | 2.5 | B   | WB-4     | 2.9 | B   |
| NB-2     | 2.6 | B   | NB-5     | 3.4 | C   |
| SB-2     | 2.9 | B   | SB-5     | 3.5 | C   |
| EB-2     | 2.3 | B   | EB-5     | 2.6 | B   |
| WB-2     | 1.5 | A   | WB-5     | 2.8 | B   |
| NB-3     | 3.5 | C   | NB-6     | 2.4 | B   |
| SB-3     | 2.9 | B   | SB-6     | 2.5 | B   |
| EB-3     | 3.3 | C   | EB-6     | 3.2 | C   |
| WB-3     | 3.2 | C   | WB-6     | 3.4 | C   |

## Validation of the Proposed Model

The proposed model is applied to the intersections I-5 and I-6 whose data was not used in the model calibration. The observed vs. predicted perception values are plotted in the validation chart shown in Figure 9.

The predicted perception values and observed perception values are validated on 45 degree line in the validation chart. The  $R^2$  value and slope of the plot obtained are 0.9638 and 43 degree respectively.

## Defining Level of Service for the Selected Crosswalks Based on Observed PV

The LOS was defined for the selected crosswalks at signalized intersections based on the pedestrian Level of Service criteria proposed in the present study and are shown in Table 9.

Table 10. Comparison results

| Author                             | Dependent variable selected for evaluating LOS | Independent variables appeared in the modeling                                                                                 |
|------------------------------------|------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| Sahani <i>et al.</i> (2017)        | Pedestrian delay                               | Platoon size, Flow rate, and walking speed                                                                                     |
| Archana and Reshma (2013)          | LOS                                            | Surface condition and pedestrian flow (Based on the rating given by pedestrians)                                               |
| Muraleethran <i>et al.</i> (2005)  | LOS                                            | Pedestrian delay and pedestrian-bicycle interactions                                                                           |
| Marisamynathan and Vedagiri (2019) | Perception value                               | Suitable gap and crossing direction. (Based on the rating given by pedestrians)                                                |
| In the present study               | Perception value                               | Vehicular characteristics and pedestrian characteristics: Pedestrian comfort and safety (based on rating given by pedestrians) |

From Table 9 it is very clear that among all the study crosswalk locations, only one crosswalk i.e., WB-2 is working under LOS A condition, 12 crosswalks are working under LOS B condition, and 11 crosswalks of the study intersections are working under LOS C condition.

## Discussion

Most of pedestrian Level of Service studies were done under western traffic conditions, where homogeneous traffic conditions prevail. Very few studies were done under heterogeneous traffic conditions. Also, the research work done under heterogeneous traffic conditions did not considered the pedestrian comfort and safety factors which are very important to consider under heterogeneous traffic conditions, especially at junctions. The present study given more importance to comfort and safety of pedestrians by evaluating perceived values. As per Indian Road Congress (IRC) the walking speed of pedestrians is considered as 1.2 m/s. But, from the present study it is observed that, the crossing speed of pedestrians at some study locations is more than the standard walking speed of the pedestrians. So, the walking speed for pedestrians is to be revised. The results of the present study are compared with the results of some of the previous studies and are shown in Table 10.

## Summary and Conclusions

The present research work dealt with pedestrian crosswalks provided at signalized intersections in heterogeneous traffic conditions. More often among all the road users, pedestrians have been given the least importance by the transport planners due to which pedestrians are involving in road accidents. The present study focussed on the parameters related to pedestrian safety and comfort at crosswalk locations of signalized intersections in Hyderabad, Warangal and Calicut cities in India. The factors affecting Level of Service of crosswalks at signalized intersections were studied and among those the important significant factors were assessed. Also, the perception values were obtained by conducting a questionnaire survey. Using perception value and significant factors, model was developed and was validated.

Based on the present research work the following conclusions are made.

1. A lower pedestrian crossing speed of 0.91 m/s was observed for South Bound crosswalk of the Gandimaisamma Intersection and a higher crossing of 1.98 m/s was observed for the crosswalks of North Bound and South Bound approaches of the Eranhipalam intersection.
2. Among all the affecting factors: pedestrian volume, crossing time, crosswalk length, crossing speed, right-turning vehicle volume, left turning vehicle volume, the significant factors identified were right-turning vehicle volume and left-turning vehicle volume.
3. The developed model in the present study showed good results when validated using data which was not used in the validation
4. The Level of Service criteria was defined for pedestrian crosswalks of study signalized intersections based on pedestrian perception values. Among 24 study crosswalks: cross walk WB-2 is working under LOS A; NB-1, EB-1, WB-1, NB-2, SB-2, EB-2, SB-3, WB-4, EB-5, WB-5, NB-6, and EB-6 are working under LOS B; SB-1, WB-2, NB-3, EB-3, WB-3, NB-4, SB-4, EB-4, NB-5, SB-5, SB-6, and WB-6 are working under LOS C condition.
5. This decreased performance of crosswalks is due to turning movements and encroaching vehicles at crosswalks of signalized intersections.

## Acknowledgments

The authors are thankful to NIT Warangal for providing support for data collection.

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