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GIS Based Evaluation of PLOS and Accessibility around Bus Stops

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Abstract

Public transport and non-motorized modes of transport are complements to each other. Large investments are made In India for the construction and maintenances of road and railway infrastructure, but inadequate pedestrian facilities discourage people to choose walking and public transport as their mode of transport. Hence, it is crucial to assess the level of accessibility and pedestrian routes near bus stations. This study examines Pedestrian Level of Service (PLOS) around the busstops and access time to reach each bus stop in Kazhakoottam, one of the fastest-growing areas of the Thiruvananthapuram district, Kerala. The manual assessment of PLOS around bus stations in a road network is very tedious. To overcome this limitation a PLOS tool is developed in GIS environment. This PLOS tool considers the main factors influencing walkability, such as walking speed, pedestrian count, space for pedestrians, and crossing time. An algorithm for access time measurement, which calculates the amount of time needed to reach each matrix cell, beginning from a transit station is developed in GIS environment. The developed PLOS tool is very effective and gives above 90% accurate results.

Keywords: GIS, Pedestrian Level of Service, Walkability, Accessibility, Public transport

1. Introduction

The goal of the transportation system is to provide safe and efficient movement of passengers and goods by different modes. Even if large investments are made in construction and maintenances of road and railway infrastructure, poor-quality pedestrian facilities discourage people to choose walking and public transport. Walking is a sustainable active transportation mode which can be incorporated into daily life and provides a number of additional benefits, such as lessening traffic congestion, lowering carbon emissions, and boosting air quality. As an active and engaging form of transportation, walking can enable people to interact with their environment and directly benefits the user by offering an accessible means to get regular physical activity (Wen et al., 2011; Moniruzzaman and Páez 2012; Wey and Chiu 2013; Adlakha and Parra 2020). Walkability is typically comprised of a combination of factors such as presence of walking facilities, safety, comfort and convenience of walking. Neighbourhood with a high level of walkability offers, people to travel by foot easily and safely (Litman 2003; Shay et al., 2003; Galanis and Eliou 2011; Leather et al., 2011).

Qualitative and quantitative evaluation of transit user facilities is important for identifying the present condition and providing adequate facilities for pedestrians. Based on various qualitative and quantitative criteria, such as walking speed, pedestrian count, comfort, space available per pedestrian, crossing time, safety, etc., the pedestrian level of service compares the level of service in an area and classifies the pedestrian conditions into different levels. The Indian Highway Capacity Manual (Indo-HCM) by the Central Road Research Institute, New Delhi (CSIR) is used as the industry standard for studying the road traffic characteristics and analysing PLOS in different condition. The Indo-HCM uses the concept of PLOS as a qualitative measure to describe, the user defined perception of how well a transportation facility or service will operate. It is classified into six service levels using a letter grade from ‘A’ to ‘F’. PLOS ‘A’ indicates free flow condition for pedestrians, with high quality facilities and PLOS ‘F’ indicate the worst condition, the flow of pedestrian exceeding the capacity. A high level of walkability condition provides an environment that pedestrians can use to walk comfortably and safely to reach their destinations (Shkari et al., 2013; Galanis and Eliou 2017; Banerjee and Maurya 2022). Bivina et al. (2018) proposed a method to assess PLOS of sidewalks using pedestrians’ perceptions towards their streets and sidewalk infrastructures.

Transit user facility studies help to assess the existing facility and serves as a manual for formulating guidelines for the facility. If the layout of transit catchment regions is unique, the network density, stopping patterns, urban gravity, and service quality possess the greatest impacts. Transit user safety and the service quality assessment is as important as that of traffic facilities (O’Connor and Caulfield 2018; Jeffery et al., 2019; D’Orso and Migliore 2019). With the depletion of natural resources, it has become a necessity to shift to sustainable modes of transport such as public transportation or Non-Motorized Modes of Transport (NMT). This brings about a need to provide safe and convenient accessibility to the transit users. This may include safe pedestrian walkways, crossings and waiting areas for the transit users. The access time to reach each service from a transit station should be minimum. It also increases the mode change from motorized to non- motorized and public transportation systems (O’Connor and Caulfield 2018).

One of the most significant aspects of the transportation system is accessibility. Public transport can be more attractive by providing “door to door mobility” and accessibility has also a considerable impact on life satisfaction in the form of perceived accessibility (Saif et al., 2018). The accessibility provides the interaction among the services situated in an area and the public transportation system serving it. There exists a strong correlation between built environment features and choice of access mode to public transit stops. Land use patterns and population densities have been found to have a major impact on trip lengths and choice of travel modes (Meurs and Haaijer, 2001; Cervero et al., 2002; Yigitcanlar et al., 2010; Ujjwal and Bandyopadhyaya 2021). Along with the mobility enhancing strategies, accessibility measurement is important for promoting NMT and public transportation facilities. The mobility enhancing strategies such as PLOS only focus on improving the pedestrian facilities such as crosswalks, sidewalks etc, but the accessibility aims to increase access to desired services, like walking from a public transportation station (Palma and Rochat, 2000; Muraleetharan and Hagiwara, 2002; Zhou et al., 2012).

Various PLOS models were developed by researchers, but they failed to provide accurate PLOS values. The GIS-based approaches are very effective for the computation of access time and quality of the pedestrian network. Due to the random probability distribution and hazy input data, the previous PLOS model, which was based on the traditional regression approach, was unable to provide accurate PLOS values (Marisamynathan and Vedagiri 2019). Hence, development of new PLOS model is required. The effectiveness of walkways and accessibility to transport hubs were evaluated using GIS, which proved to be a useful tool. Decision-making processes were improved by using GIS tools in transportation studies. Utilizing GIS techniques can easily assess the key features of pedestrians and the pedestrian amenities, and the actual level of service for pedestrian facilities was determined based on the quantity of pedestrians using the sidewalk, pedestrian speed, etc. (Rossetti et al. 2020; Muraleetharan and Hagiwara 2002; Telega et al., 2021). The overall LOS of the urban walking environment have major influence on pedestrian route choice behaviour. Hence integration of PLOS model with GIS will provide better analysis.

Many countries and cities have long-held goals for sustainable transportation, which include limiting traffic growth and greenhouse gas emissions from transportation. India is one of the major contributors of greenhouse gases, therefore switching from motorized to non-motorized and public transportation is necessary to reduce pollution, traffic congestion, and greenhouse gas emissions (Guttikunda and Mohan 2014; Sharma et al., 2019). Use of Public transportation and NMT improves the quality of life and limits the congestion, pollution etc. Improving public transportation infrastructure alone may have marginal effect on overall reduction of CO_2 emissions and adverse effects on traffic safety. In order to attract more people towards sustainable modes of transport, safe and efficient transit user facilities have to be provided. The first and foremost step to achieve this is finding the level of service of present transit user facilities and also identifying the level of accessibility offered by the public transport system. It is difficult for a large network to evaluate the region's PLOS and accessibility manually (Tiwari et al. 2015). Hence GIS-based techniques are used for assessing the effectiveness and accessibility of the pedestrian network in the research region. The present study contributes to the literature by developing a GIS tool for assessing the quality of pedestrian network using PLOS method and evaluating pedestrian accessibility around bus stops.

The paper is organised as follows. Section 2 explains the outline of the methodology used and study area. Section 3 and 4 deals the evaluation of pedestrian LOS and access time in which the development of PLOS tool and access time computation were discussed. Section 5 discuss the findings of the work and concluded in section 6.

2. Methodology of the Study

This study aims to develop a PLOS tool for assessing the quality of pedestrian networks and evaluating the pedestrian accessibility around bus stops using recursive algorithm. Major bus stations in Kazhakootam were chosen as the study area. The GIS environment was used to identify various approaches for figuring out the transit users' level of service and the access time from the transit station. A PLOS tool created in the ArcGIS software is used to determine the quality of service provided to pedestrians in the area by considering the local contributing elements and analysing the various research methodologies from the past. The access time from a bus station to the nearby areas was computed by assigning the crossing speed of pedestrian to every cell and the recursive algorithm was used for the same.

ArcGIS software was used to digitize the road network and bus stops in the field of study. The developed GIS tool computes the PLOS by comparing the collected results with those of the range of values provided in the Indo HCM (2012-17). Modified recursive algorithm was used for the computation of pedestrian access time. The crossing speed of pedestrians depends upon the land use of the area. Figure 1 shows the general methodology adopted for the study and each step is described in the following subsection.

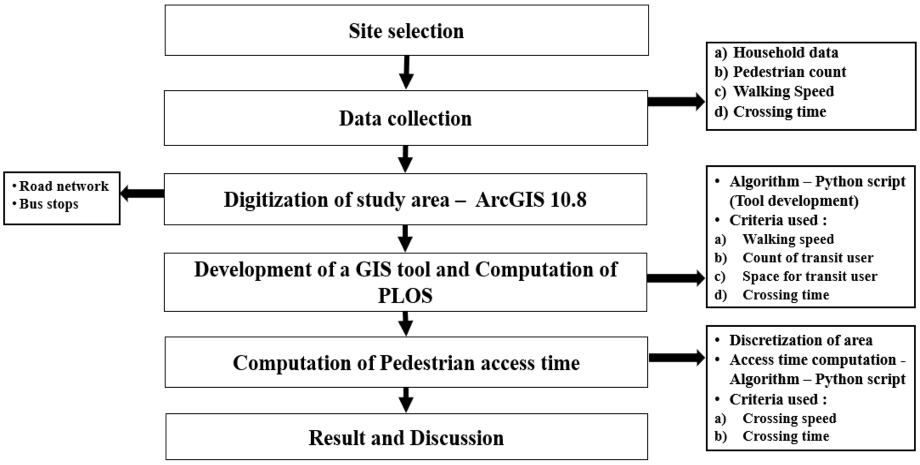


Figure 1: Methodology of the study

2.1 Study Area

Study area selected was Kazhakootam ward, one of the fastest growing areas of the Trivandrum district. Figure 2 shows the ward map of the study area. The study area has a total population of about 47,592 (as per census data 2011). It is situated between 8◦33’27.657 ”N and 8◦34’53.947”N latitude and 76◦51’21.443 ”E and 76◦53’29.716”E longitude. The area was selected because it had high volume of transit users and perceived a poor pedestrian level of service. The demand for public transportation in the area was observed to be very high because of the presence of Technopark, academic institution such as Sainik School, KINFRA apparel park, etc. Figure 2 shows the map of the study area.

Main bus stops near to the technopark area were identified where transit user demand is greater than the facilities provided. It is also observed that there are no sidewalks provided in the area and the vehicular volume and speed are very high.

2.2 Data Collection and Analysis

Data collection included a household survey and pedestrian characteristics survey. The household survey was done using a predefined questionnaire. The questionnaire was prepared after a pilot survey and the data provided information about the trip characteristics, the problem faced by the transit user, socio-economic characteristics, etc.

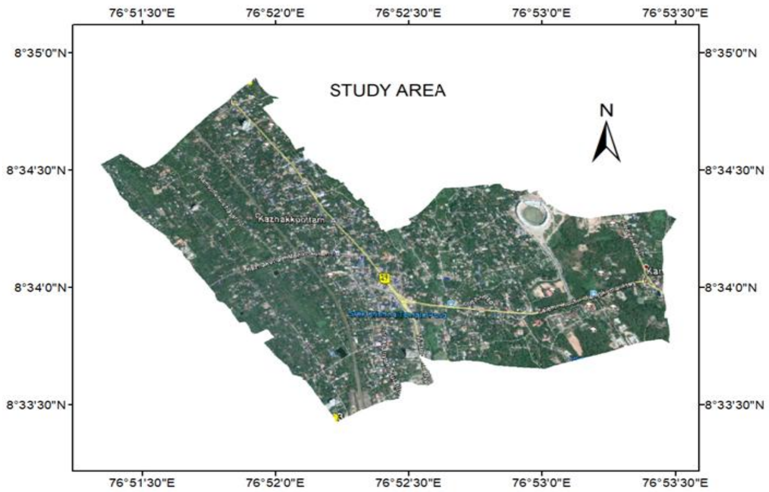


Figure 2. Study area

The walking speed of pedestrians was found out to determine how safe the walking conditions were. If people are able to walk with ease, it would mean that the safety of the pedestrian facility provided is appropriate. If proper width, walking floor, and separation are given for pedestrian walkways, the pedestrians can walk without any difficulty and if the walking speed of pedestrians is high, then greater the efficiency of the system. Hence it can be considered as a major criterion to evaluate the pedestrian level of service. Speed of transit users was found out by fixing two points which are at a known distance apart and recording the time taken by the users to cross the two points. The ratio of distance to the time taken would give the speed of the transit users. The data was collected near the prominent bus stops of Kazhakootam ward.

Pedestrian count at the bus stops was recorded to know if a proper waiting shed area is present to meet the demand for public transportation. The area of bus stops provided was measured and the space provided per pedestrian was calculated. The number of people entering the bus stop per minute was recorded. The area divided by the number of users gave the space per pedestrian. It is also the main criterion for computing the pedestrian level of service computation.

Crossing time was another important factor. If adequate signals are provided exclusively for transit users, the crossing time can be considerably reduced and the safety of pedestrians can be increased. Crossing time was found at places where pedestrian crosswalks are provided and also at locations where there is a major demand for crossing the road but lacked crosswalks.

2.3 Digitization of Study Area

The road network of Kazhakkootam was prepared using Arc GIS software. (Fig. 3(a)). Existing bus stops in the area were also digitized using the latitude and longitude data from GPS. Major bus stops in the study area were identified for this study and are given in Fig. 3(b).

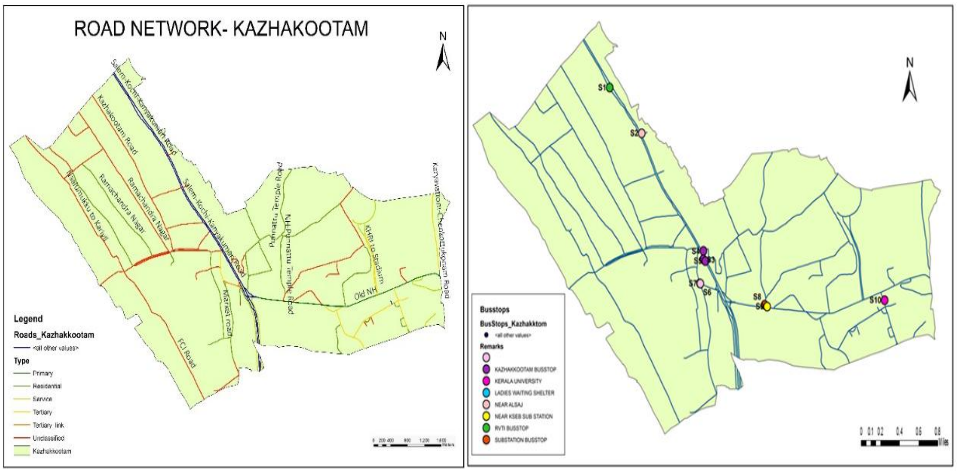


Figure 3(a): Major road network present in the study area and 3(b): Bus stops selected for the study.

2.4 Development of the PLOS tool

The GIS based PLOS tool determined the LOS of the amenities provided for pedestrians. A program was created in GIS context to overcome the tediousness occurred in the manual calculation of transit station’s PLOS. The PLOS tool was developed using a Python script algorithm and it was built on ArcGIS software. PLOS tool computes the PLOS of present transit user facilities of the area by comparing the standard values in the Indian Highway Capacity Manual (Indo-HCM) 2012-17. Based on Indian traffic and pedestrian conditions, it comprises of standard values for speed, space allowed per pedestrian, pedestrian flow rate, and crossing time taken against various LOS gradients. The following criteria are utilised in the calculation of PLOS;

- Waking speed
- Pedestrian count (flow)
- Space of transit user
- Pedestrian crossing time

The PLOS tool allows the computation of PLOS based on individual factors as well as the transit station’s overall PLOS.

2.5 Computation of pedestrian access time

Figure 4 shows the flow chart for the computation of pedestrian access time. A land-use map of the study area is important to calculate the access time near the bus stops. The accessibility and the land use of an area are interconnected. ET- Geowizard tool, a free extension of ArcGIS software was used for the discretization of the study area. The vector grid tool automatically creates a polygon vector grid using user-defined extends and cell size. Each transit node was surrounded by a polygonal shapefile, which was then examined using cells with a 20 × 20 m size. The ET-Geowizard tool creates two types of identifiers in the attribute table of the vector grid for each record: a ”ET ID” field that provides the identification number of each cell and a ”ET Index” field that contains the field and the record of the cell in the matrix. It is regarded as a crucial field because ET Index creates a potential connection between the computing algorithm and the shape file.

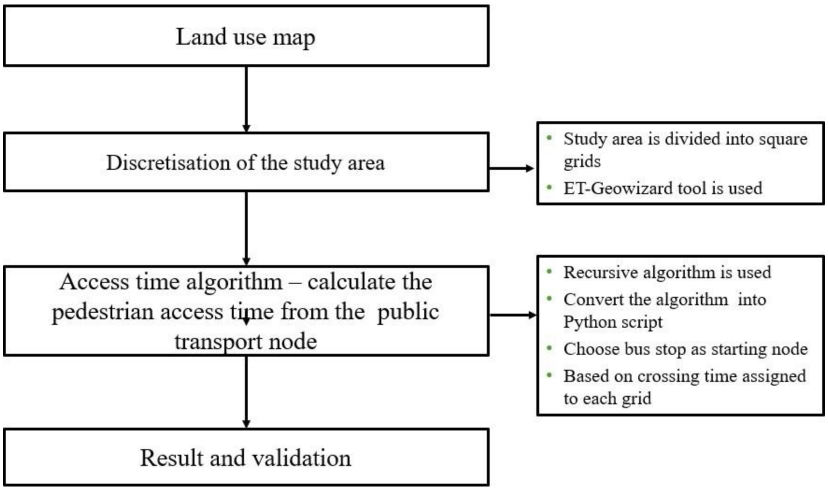


Figure 4: Flow chart of computation of access time

The next step was to link each cell to the information in the land use map of the study area. According to Rossetti et al. (2020), the pedestrian crossing speed was used to determine the pedestrian crossing time value for each cell (Table 1). The ratio of cell size to the associated cell’s crossing speed was used to calculate the pedestrian crossing time.

Table 1: Pedestrian crossing speed

Land use	Crossing speed (km/hr)
Roads	3.6
Public spaces	3
Parks and recreational areas	2
Others	0

Based on the information layers in each cell, the algorithm was created as a Python script and executed in ArcGIS software. It assigns each cell a pedestrian crossing time and assesses the connections existing between the starting node and the cells nearby. The bus station’s cells in the grid are identified and selected as the algorithm’s beginning nodes. With the help of this model, the timing of pedestrian access to each cell from a bus stop can be displayed on thematic maps.

3. Evaluation of pedestrian LOS

A Python script algorithm was used to develop the GIS-based PLOS tool for calculating the level of service of pedestrians around transit stops. The ArcGIS software allows the development of new tool using python script. The PLOS tool-based computation gives quick and accurate results for each bus stops.

3.1 Criteria for PLOS computation

The PLOS tool computes the pedestrian level of service by comparing the values obtained with the criteria given in Indo-HCM 2012-17 (Table 2 and 3)

Table 2 PLOS criteria for footpath

PLOS	Speed (m/min)	Space (m^2/ped)	Flow (ped/min/m)
A	> 61.5	> 4.87	<= 13
B	> 59.7 - 61.50	> 3.07 – 4.87	> 13 – 19
C	> 56.50 - 59.67	> 1.87 – 3.07	> 19 – 30
D	> 45.14 – 50.84	> 1.07 – 1.87	> 30 – 47
E	> 29.11 – 45.14	> 0.47 – 1.07	> 41 – 69
F	< 29.11	<= 0.47	> 69

Table 3 PLOS criteria for crosswalks

PLOS	Pedestrian delay (S)
A	< = 5
B	5 – 10
C	11 – 25
D	26 – 45
E	46 – 80
F	> 80

3.2 Development of Algorithm for the PLOS Tool

The PLOS tool mainly consists of two parameters such as input and output feature class. The working of tool is set such that, the input feature class can be added by the user and output feature class may be user defined or set as default. By using the tool, ArcGIS software automatically computes the PLOS values of individual criteria such as speed-based, space-based, crossing time-based PLOS, etc and the overall level of service of the transit station based on the minimum level of service values of individual factors. Figure 5 shows the PLOS tool developed in ArcGIS software. The algorithm can be expanded to more criteria and big networks as well. This study takes into account the factors that have an impact on the level of service provided to pedestrians. The input feature class and output feature class are the parameters of the PLOS tool.

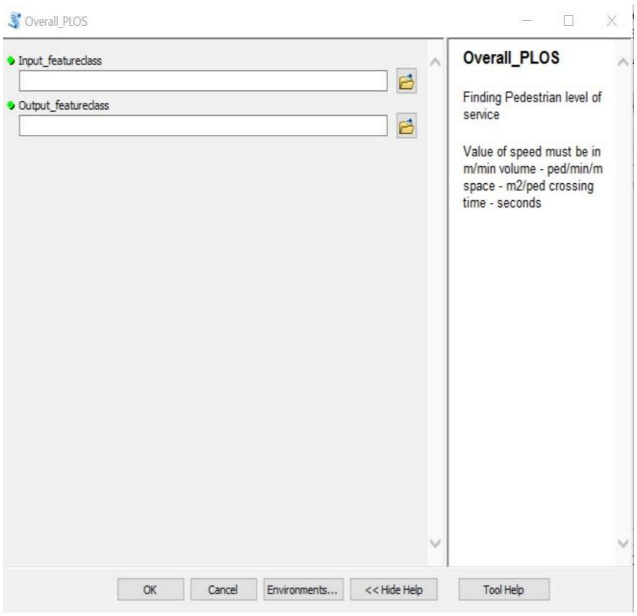


Figure 5: PLOS tool

4. Computation of Pedestrian Access Time

The majority of the study region is within agricultural fields and built-up areas, according to the analysis of the land use map. The land use map for the study area is displayed in Figure 6(a). The area is divided into a square grid of having 20098 cells using the vector grid tool of ET- geowizard tool. The size of a single cell is 20x20 m. For each grid, the crossing time value is assigned based on the crossing speed value (Table 1). Figure 6(b) shows the grid map of Kazhakootam.

The recursive algorithm was modified into a python script for the computation of pedestrian access time. Starting from a designated cell, the algorithm calculates the amount of time required to reach each matrix cell. The time needed to reach a distance of 0.1, 0.2, 0.5, 1, 1.5, and 2 km from a transit station was computed. This is based on the crossing time which is assigned to each cell. The major bus stop in Kazhakootam (S3 in fig. 3(b)) is used as starting node for running the algorithm. After assigning crossing time to each cell, the ET-Index (attribute table) value of the bus stop is chosen as starting node to run the algorithm.

Figure 6: (a) Land use map

Figure 6: (b) Grid map of Kazhakootam

5. Results

Developed PLOS tool is demonstrated using the data obtained from the study area. The pedestrian walking speed, pedestrian count, space, and crossing time corresponding to each bus stops were added to the attribute table of the digitized map. Four bus stops such as S3, S4, S5 and S6 were selected for the same. Table 4 shows the observation from the study. Pedestrian level of service was found out based on the standard values of walking speed, crossing time, space per pedestrian, and volume count provided in the Indo-HCM 2012-17 using the PLOS tool. The obtained PLOS based on individual criteria of the transit stations is shown in Fig.7(a),(b),(c), and (d). Fig.7(e) shows the overall PLOS around the transit station. The accessibility around selected bus stops through walking can be easily identified using the developed pedestrian access time algorithm. Figure 8(a) shows the access time around the bus stops.

5.1 Validation of the Pedestrian Access Time Algorithm

Accessibility was assessed by validating the access time algorithm, to know the accuracy. Data from a household survey of sample size 1042 in the study area was used for validation purpose. It includes walking time and respective walking distance and a graph is plotted to compare the results. 20% of the data from the household survey was used for validation. Results show that, the algorithm provides similar results to that of survey data for a distance up to 0.5 km. The algorithm shows higher access time compared to original data, with percentage error of 34.82% for distance greater than 0.5km. Figure 8 (b) shows the comparison of survey data and results from access time algorithm.

Table 4. PLOS at the transit stations

CRITERIA	BUS STOPS							
	S3		S4		S5		S6	
	Value	PLOS	Value	PLOS	Value	PLOS	Value	PLOS
Walking speed of pedestrian (m/min)	74.4	A	75	A				
Pedestrian count (ped/min/m)	22.21	C	50.67	E	83.75	F		
Space per pedestrian (m2/ped)	0.57	F	0.72	F	0.14	F		
Crossing time (s)	52.28	A					48.44	A
Overall PLOS around bus stops	F		F		F		A	

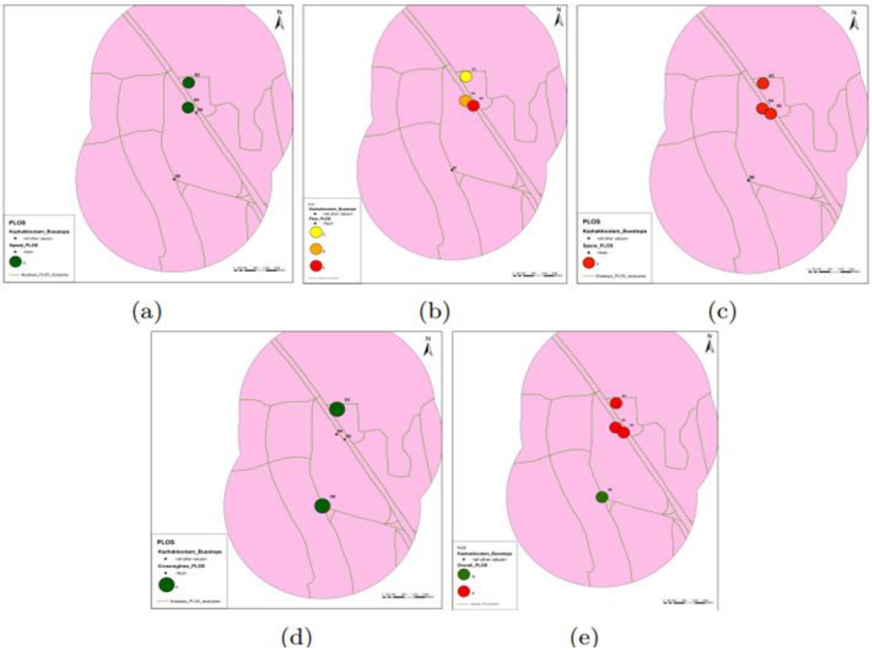
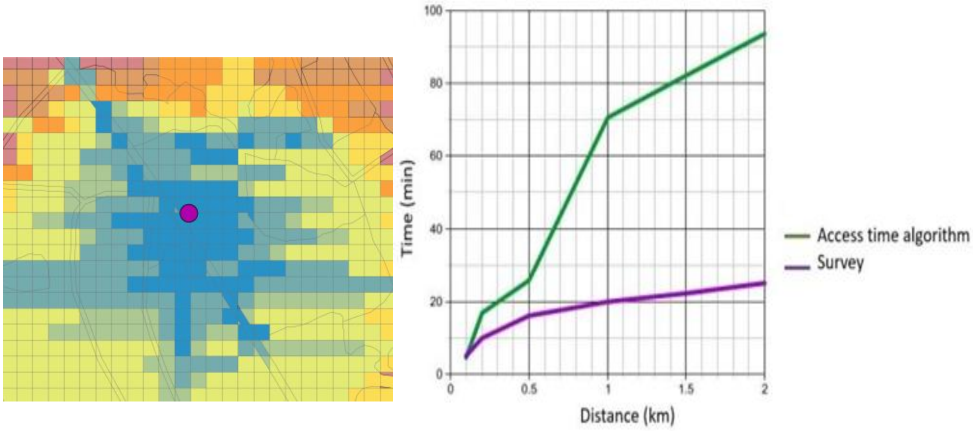


Figure 7: PLOS in the study area based on (a) Walking speed, (b) Pedestrian count, (c) Space per pedestrian,(d) Pedestrian crossing time, and (e) Overall PLOS in the study area



(a) (b)

Figure 8: (a) Access time to reach various cells from the node (b) Validation of the algorithm

6. Conclusion

The quality of transit user amenities must be enhanced in order to attract more passengers and ensure the sustainability of a region's transportation network. To attract more users, the existing pedestrian characteristics and conditions of the area is to be studied. The pedestrian level of service was determined by taking into account factors including the number of pedestrians, the walking speed, the speed at which they cross the street, and the amount of space provided per pedestrians. The tedious procedure of pedestrian level of service computation was eliminated by the introduction of a new PLOS tool. The PLOS tool gives accurate pedestrian level of service around the transit stations. Overall PLOS around every bus stops will be obtained in least time by the developed tool. The python-based PLOS tool is very effective and ideal in the computation of PLOS around bus stops and it gives the better results than other methods. In order to compute the pedestrian level of service based on other criteria given in Indo-HCM 2012-17, this tool can be expanded to a large network. The accessibility around the bus stops is sufficient to meet the services in a limited time. The algorithm gives access time to reach each grid from a bus stop. The algorithm works based on the crossing time of each point and it directly relates to the land use of that area.

The study area is a commercial area and so many services are present in door-to-door mobility, but the pedestrian facilities are very poor and it will discourage people to choose public transportation and walking. It can be concluded from the study that the bus stop area was not satisfying the demand of the transit users in the area. The primary issues faced by the transit users are the difficulty of crossing, the lack of adequate space and amenities in the waiting shelters, the inability to park buses, etc. Due to high speed of vehicles through the main road, it is difficult for the transit users to walk through the sides. This brought in the need to provide sidewalks throughout the main roadside. These suggest the need to improve the facilities in the area. The facilities to be provided include proper, safe, and continuous sidewalks, etc.

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