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Development of Composite Pedestrian Level of Service Model in Urban Milieu at Midblock Sections

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Abstract

The pedestrian mode is gaining recognition as a basic building block in urban system design. Increasing attention is being given to developing vehicle-free zones to reduce urban pollution and return the inner city to its former role as a place for personal interaction. Attempts are being made to improve the walking experience, to make it more safe, convenient, and attractive especially in urban milieu to promote sustainable development. To provide the best pedestrian environment, it is necessary to understand pedestrian level of service. Conventional techniques of LOS determination consider the basic mobility characteristics of the pedestrian. The objective of this study is to develop a more accurate method of estimating level of service of pedestrians by developing composite indicators that integrate both qualitative and quantitative factors affecting both pedestrian and roadway conditions in the pedestrian movement. The relative importance of these multifaceted factors is assessed using Saaty scale and an Analytic Hierarchy Process is applied to determine the level of service. Field investigations include road network characterization and inventory studies, vehicular / pedestrian traffic characterization studies, pedestrian opinion surveys, expert opinion surveys. The approach has been applied to a major arterial road in Hyderabad city, Telangana, India in Mehdipatnam zone where pedestrian interactions are relatively high due to the commercial activity along the corridors. The stretches considered in the study exhibited Level of service "B" and "C" which implied necessary improvements to promote a good level of service.

Keywords

urban milieu, Saaty scale, Analytic Hierarchy Process

1 Introduction

Green initiatives in urban transport are widely adopted in many developed countries to promote sustainable development. Pedestrianization is an effective and strategic design module in urban milieu models that helps in reducing vehicular emissions and promoting green environment (Jou, 2011). They should be considered as priority corridors that must be made barrier free with good level of service. In order to provide the best pedestrian environment, it is necessary to understand pedestrian level of service. Conventional techniques of LOS determination consider the basic mobility characteristics of pedestrians. There is a need for updating the existing approaches considering composite indictors that influence the pedestrian movement in urban environment. Since the policies are based on supply system enhancement with a focus on only a single entity of link in a network, a holistic view of pedestrian facilities considering network is lacking. This study presents a more accurate method of estimating level of service of pedestrians by developing composite indicators that integrate both qualitative and quantitative factors affecting both pedestrian and roadway conditions in the pedestrian movement.

Many comprehensive studies were conducted to evaluate pedestrian LOS using qualitative and quantitative variables (Al-Azzawi and Raeside, 2007; Jensen, 2007; Petritsch et al., 2006; Sisiopiku and Byrd, 2006; Sisiopiku et al., 2007). The quantitative parameters were mostly basic mobility characteristics like speed, flow and density whereas qualitative parameters were based on pedestrian perception in the facilities. Marisamynathan and Vedagiri (2019) have developed perception-based level-of-service model at signalized intersection crosswalks with respect to pedestrian safety, convenience, and efficiency at signalized intersections using fuzzy linear

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regression analysis. Sahani and Bhuyan (2014) have used four measuring parameters i.e., average pedestrian space, flow rate, speed of pedestrian and volume to capacity ratio for determining pedestrian level of service using three methods of clustering i.e., Affinity Propagation (AP), Self-Organizing Map (SOM) in Artificial Neural Network (ANN) and Genetic Algorithm Fuzzy (GA-Fuzzy) clustering. This analysis was used for validation of mid-sized cities in India and has recommended a more comprehensive approach for bigger cities. A participatory multicriteria decision analysis approach is used by Gonzalez-Urango et al. (2020) for the planning and designing of pedestrian routes using social network analysis (SNA) and analytic network process (ANP). Raad and Burke (2018) have extensively made a systematic review of pedestrian LOS estimation studies and have grouped the factors in three themes i.e., Comfort, safety and mobility. The most used factors were footpath width, obstructions to pedestrian flow, motor vehicle speeds and volumes, shoulder widths, and buffers such as on-street parking. Ahmed et al. (2021) has considered 17 factors for determining LOS using analytical point system to compare existing street crossing conditions to the guidelines' standards. Survey results show that the provision of a zebra crossing was the most critical indicator at the pedestrian crossings, while drainage near crosswalks was regarded as the least important. Very few models were developed based on both quantitative and qualitative variables. There is a need to develop a composite model that evaluates pedestrian environment from multiple facets.

2 Objectives of the study

Following were the objectives framed in the study:

1. Development of a generalized approach for determination of pedestrian level of service for mid blocks in urban area.
2. Identification of factors that influence pedestrian level of service that relate to pedestrians, roadway and vehicular traffic.
3. Application of multi criteria analysis through Analytic Hierarchy Process for synthesizing the various criterions affecting pedestrian LOS.

3 Assumptions in the study

Following are the assumptions framed in the study:

1. The functional attributes within each segment of the stretch are uniform.
2. Qualitative attributes considered in the analysis are assumed based on the scenarios in the study stretch.
3. The attributes taken in the analysis are taken for peak hours.

4 Methodology and data analysis

The process of the collection of data, computations and analysis has been mentioned in detail in the following steps. Field investigations include road network characterization and inventory studies, vehicular / pedestrian traffic characterization studies, pedestrian opinion surveys and expert opinion surveys.

4.1 Identification of study area and delineation of study stretches

The study area is selected based on the pedestrian movements where crosswalk and sidewalk traffic is relatively high on midblocks which are straight sections of roads between two intersections. The study stretches are delineated along the commercial activity corridors, mostly on the functional stretches like arterial and sub arterial roads in the urban area. Mehdipatnam zone, Hyderabad, Telangana, India is taken as the study area in which the study stretch is further divided into 3 micro segments from NMDC to Falcon, Falcon to SD hospital, SD hospital to Mehdipatnam Rythu bazaar. The location of the study area is shown in Fig 1. The picture of the study area is shown in Fig. 2 to 4.

4.2 Formulation of level of service characteristics

The various factors that can be considered in the development of the model are grouped into two main categories, as Pedestrian characteristics and Roadway characteristics.

Fig. 1 Location map of the study stretches

Fig. 2 Pedestrian traffic during peak time in Mehdipatnam

Fig. 3 A view of the study area, Mehdipatnam bus depot with Auto parking and criss cross pedestrian movements

Fig. 4 Pedestrian crossing with no signal at Mehdipatnam

The pedestrian factors considered for the study relate to pedestrian mobility, safety, comfort, behaviour, satisfaction whereas roadway factors relate to roadway geometric/pavement conditions, traffic characteristics, land use characteristics and driver attributes. The description of the characteristics is given below.

4.2.1 Pedestrian factors

The pedestrian characteristics are the facilities related to pedestrians and include the attributes that are from the perception of pedestrians. Pedestrian characteristics are categorised into six characteristic groups: mobility characteristics, safety characteristics, comfort characteristics, pedestrian behaviour, satisfaction and facility geometrics. The pedestrian factors considered in the study are shown in Table 1 below. The surveys used to determine the characteristics are also indicated in Table 1. The description of the attributes considered for analysis and the criteria for normalisation of each attribute is also presented in Table 1.

Mobility characteristics

Mobility characteristics of pedestrians are the factors that relate to the movement of pedestrians in the stream. The determination of each characteristic is given below:

1. Pedestrian walking speed:
   Pedestrian walking speed is computed by noting the time taken by the pedestrian to cross a specific distance. Frequency of speeds is computed, cumulative frequency graph is plotted and the speed corresponding to 98% is noted.
2. Pedestrian volume:
   Pedestrian volume is computed by the number of pedestrians crossing a point under consideration. A graph of number of pedestrians versus duration is plotted and peak volume hour is noted. A volume of 800 indicates good level of service for a sidewalk width of 1.5 m and 1,600 for a sidewalk width of 2 m.
3. Critical gap:
   Critical gap of pedestrians to cross the vehicular traffic is determined with two datasets. In the first dataset, the pedestrian arrival time at the crossing and departure time while leaving the stream are noted. In the second dataset, the vehicular arrival pattern is noted by noting the arrival time at a specified point near the pedestrian crossing. For each gap size the total number of acceptances and rejections are determined. A graph is drawn between gap size and number of acceptances and rejections. The sample gap for a stretch is shown in Fig. 5.
4. Pedestrian crossing time:
   Crossing time is the time taken by the pedestrian to cross the road. A value of 25 sec is 100 and a value exceeding 50 is considered as zero.
5. Average pedestrian delay:
   Average pedestrian delay is the delay for a pedestrian to cross the road. It is computed by considering the gap size available for the pedestrian to cross the road as the vehicles pass by. A delay of zero is 100 and a value of 90 sec is zero. The average pedestrian delays are converted to a scale of 100 by taking the above limits.
6. Continuity of walking:
   Continuity of walking is defined as the ease with which a pedestrian can walk continuously. It is computed based on ratings to a scale of 0 to 5 and are obtained from pedestrian response survey. An upper limit of 5 is considered equal to 100 and a value of zero is taken as lower limit.
7. Walk density:
   Walk density is the number of persons in a given area. A density over an area of 10 m^2 is considered for different stretches. A density of 30 is taken as equal

Table 1 Pedestrian characteristics considered in the study

Stretch number	Pedestrian characteristics	Sub characteristics	Surveys organised to collect the data
1	Mobility characteristics	Pedestrian walking speed	Pedestrian speed studies
		Pedestrian volume	Pedestrian volume studies
		Critical gap	Gap acceptance studies
		Pedestrian crossing time	Pedestrian delay studies
		Average pedestrian delay	Pedestrian delay studies
		Continuity of walking	Road inventory studies
		Walk density	Photographic method
		Suitability of walk signal time	Pedestrian opinion surveys
2	Safety characteristics	Presence of sidewalk	Road inventory studies
		Presence of zebra crossing	Road inventory studies
		Presence of manned control	Field observations
		Presence of all red signal at intersections	Field observations
		Presence of sign boards	Field observations
3	Comfort characteristics	Sidewalk or cross walk surface condition rating	Pedestrian opinion surveys
		Noise level rating	Field observations
		Presence of access for disabled	Field observations
		Visibility of traffic lights	Field observations
		Degree of number of obstacles	Pedestrian opinion surveys
		Existence of pedestrian refuge islands	Field observations
		Degree of maintenance of free walking speeds	Pedestrian opinion surveys
4	Pedestrian behaviour	Pedestrian observance of law	Field observations
5	Satisfaction	Pedestrian satisfaction score	Pedestrian opinion surveys
6	Facility geometrics	1. Pedestrian area/road area	Road inventory studies
		2.Cross walk width	
		3. Length of pedestrian crossing	
		Continuity of side walk	Pedestrian opinion surveys

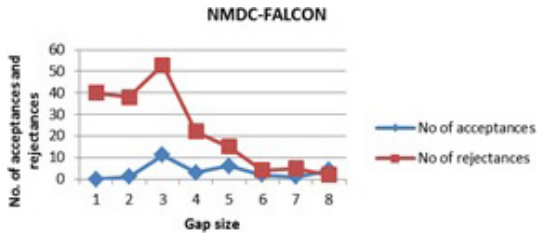

Fig. 5 Variation of gap size with number of acceptances and rejections for stretch 1

to 100 and a value of zero as zero and based on these limits the values are converted to a scale of 100.

8. Suitability of walk signal time:
   Suitability of walk signal time is determined from field observations and ratings to a scale of 0 to 5 from pedestrian response surveys. Here, a rating of 5 is indicating that the suitability is the best whereas, a rating of 0 indicates that the signal time is not suitable for the pedestrians to cross the road. Hence a rating of 5 is made equal to 100 and a rating of zero is considered as zero.

Safety characteristics

Safety characteristics are the characteristics that facilitate safety of the pedestrian. There are five characteristics considered under safety: presence of sidewalks, presence of zebra crossing, presence of manned control, presence of all red signals at intersections and presence of sign boards:

1. Presence of sidewalks:
   Presence of sidewalks indicates better level of service. A value of 100 is given if sidewalk is present in a stretch and a value of 0 is given if sidewalk is absent.
2. Presence of zebra crossing:
   Presence of zebra crossing indicates better level of service. A value of 100 is given if zebra crossing is present in a stretch and a value of 0 is given if zebra crossing is absent.
3. Presence of manned control:
   Presence of manned control indicates better level of service. A value of 100 is given if manned control is present in a stretch and a value of 0 is given if manned control is absent.

4. Presence of all red signals at intersections:
   Presence of all red signals indicates better level of service. A value of 100 is given if all red signals are present in a stretch and a value of 0 is given if all red signals are absent.
5. Presence of sign boards:
   Presence of sign boards indicates better level of service. A value of 100 is given if sign board is present in a stretch and a value of 0 is given if sign board is absent.

Comfort characteristics

The comfort characteristics are related to the perception of the users and are obtained from the intercept surveys through the rating. There are six factors considered under comfort characteristics. Existence of pedestrian refuge islands and presence of access for disabled people are observed from the field observations:

1. Sidewalk or cross walk surface condition rating:
   Good surface condition indicates better level of service. It is represented in terms of rating of 1–3 where 3 indicates a good surface condition and 1 indicates a poor surface condition.
2. Noise level rating:
   Higher noise levels indicate poor level of service. Noise level in different stretches is represented in the form of rating of 1–3 where a rating of 3 indicates less noise level, a rating of 1 indicates more noise level and 2 being the intermediate value.
3. Presence of access for disabled people:
   Presence of access for disabled people is important for better level of service. A value of 100 is given if access is present in a stretch and a value of 0 is given if access is absent.
4. Visibility of traffic lights:
   Visibility of traffic light is important for having good level of service. A rating of 1–3 is given where a rating of 3 indicates better visibility level, a rating of 1 indicates less visibility and 2 being the intermediate visibility.
5. Degree of number of obstacles:
   Degree of number of obstacles is represented as percentage of interferences in the path of pedestrians making it difficult for the pedestrians to access the sidewalks and cross walks. It is measured in a scale of rating from 0 to 100.
6. Existence of pedestrian refuge islands:
   Presence of refuge islands is an indication of better level of service. A value of 100 is given if a refuge island is present in a stretch and a value of 0 is given if it is absent.
7. Degree of maintenance of free walking speeds:
   Maintenance of free walking speeds is the ability of a pedestrian to maintain their speed throughout the sidewalk or crosswalk. It indicates better level of service of a road. The information is in the form of ratings obtained from pedestrian responses where the rating of 5 is best and rating of 0 is worst.

Pedestrian behaviour characteristics

Pedestrian behaviour characteristics are assessed through pedestrian observance of law through a rating system based on field observations:

1. Pedestrian observance of law:
   Pedestrian observance of law is an important factor in determining the level of service of a road. A rating to scale of 1–3 is given based on field observations, where 1 indicates poor observance of law, 3 the better observance of law and 2 being the intermediate value.

Satisfaction characteristics

Satisfaction is assessed through a score or a rating system by the pedestrians which is a qualitative measure of the perception of the pedestrians.

1. Pedestrian satisfaction score:
   It's ultimately the pedestrian satisfaction that is very important in the case of determining pedestrian level of service. A satisfaction score is given based on pedestrian response sheets. A rating of 1–3 is given with 1 indicating less satisfaction, 3 is more satisfaction, while 2 is the intermediate value.

Facility geometrics characteristics

Facility geometrics characteristics are measured in four parameters which refer to the facilities on the road provided exclusively for the pedestrians. All the parameters are quantitative measurements obtained from the road inventory surveys except the parameter named continuity of sidewalk:

1. Pedestrian area/road area:
   Road area includes the carriage way, shoulders, kerb, footpaths, while pedestrian area includes the foot paths and crossings etc. Pedestrian area to road area indicates the extent to which the road is being used for pedestrian needs.
2. Cross walk width:
   Cross walk width is used to determine the level of service. All the widths less than or equal to 2 m are taken equal to 100 scale.

3. Length of pedestrian crossing:
   Length of pedestrian crossing is usually less than or equal to the midblock length.
4. Continuity of sidewalk:
   Continuity of sidewalk indicates better level of service. A rating of 1–3 is given with 1 indicating less continuous, 3 is more continuous sidewalk and 2 is the intermediate value.

4.2.2 Roadway factors

Roadway factors are the factors pertaining to the road and are divided into 3 main categories – Roadway geometrics, vehicle traffic and land use characteristics.

Roadway geometrics

There are seven parameters considered under roadway geometrics:

1. Number of lanes:
   The more the number of lanes the greater the capacity of the road. A 4-lane road is assumed to be 100 and a 6 lane road as 50.
2. Roadway width:
   Roadway width is the width of the midblock.
3. Pavement surface condition rating:
   Good surface condition indicates better level of service. It is represented in terms of rating of 1–3 where 3 indicates 100, 1 indicates 0 and 2 indicates 50.
4. Number of access points:
   The more the number of access points, the lower the level of service of the road because of more interference with the pedestrian movement. An access point of 1 is taken as equal to 100, 10 is taken as equal to zero in representing the data to a scale of 100.
5. Presence of bus stops:
   Presence of bus stops is considered in a rating of 0 to 100 where 100 is given for presence of bus stops and a rating of zero in case of absence of bus stops.
6. Interference of parking:
   The less the interference to pedestrian movements, the higher the level of service.
7. Percentage of heavy vehicles and fast-moving vehicles on road:
   Percentage of heavy vehicles and fast-moving vehicles on road are determined from classified volume count data. The traffic composition is determined and the percentage of heavy vehicles and fast-moving vehicles on the road is obtained. The more the number of fast and heavy vehicles the lower the level of service of pedestrians.

Vehicle traffic

Mobility characteristics of the vehicular traffic are measured in terms of volume, speed and headway:

1. Volume:
   The volume count of vehicles is obtained from videos recorded in the stretches. Different vehicles are converted to PCU and peak hour is determined.
2. Speed:
   Vehicle speed is determined by considering the time taken by vehicles to cross a particular distance and corresponding speeds are noted. A cumulative frequency graph is plotted and a speed corresponding to 98% is taken. The cumulative speed variation of vehicular traffic in stretch 1 is shown in Fig. 6.
3. Headway:
   Headway is defined as the gap available between two vehicles and headway of 10 is taken as 100 and a value of 0 is taken as 0. Headways are determined from the vehicle arrival rate.

Land use characteristics

The land use characteristics considered in the study are the type of land use activity, intensity of land use and presence of encroachments along the road.

1. Type of land use activity:
   Type of land use indicates purpose for which the land is being used. Different categories include residential, semi residential and Commercial. A value of 100 is given for residential areas, 0 for commercial areas while 50 for semi residential areas.
2. Intensity of land use:
   Intensity of land use implies the extent to which the land is being used for different purposes. A value of 100 is given for less intensity and 0 for more intensity.
3. Encroachments:
   Encroachment on road implies less level of service. Based on field observation the percentage of encroachments are noted. A value of 100% is taken as equal to 0 and a value of zero % is taken as 100.

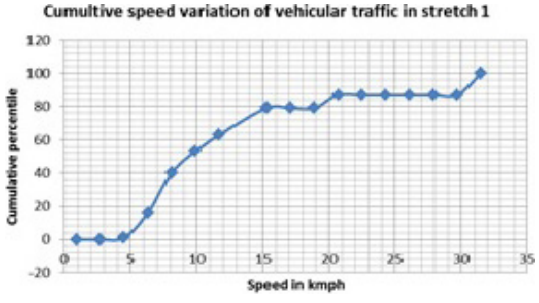

Fig. 6 Cumulative speed variation of vehicular traffic in stretch 1

4.2.3 Others

Two other characteristics such as car drivers' observance of law and degree of conflicts with pedestrians which cannot be grouped under the pedestrian, roadway, vehicle and land use characteristics are grouped under others:

1. Car drivers' observance of law:
   Car drivers' observance of law is based on field observations on a rating of 1–3. A value of 100 is assigned to a rating of 3, a value of 50 to a rating of 2 and zero to a rating of 1.
2. Degree of conflicts with pedestrians:
   The more the number of conflicts to the pedestrians the less the level of service of road. Degree of conflicts are represented in terms of percentages and are converted to a scale of 100 taking 100% as 0 and zero percentage as 100.

The LOS attributes for the three stretches, Stretch 1 (S1), Stretch 2 (S2) and Stretch 3 (S3) obtained from the above analysis is tabulated below in Table 2.

4.3 Normalisation of raw data collected from field study

The different input variables have different ranges. When they must be used for computation in a relation, they must be normalized. The raw data collected from the field studies are in different scales and must be normalized in the range of 0-100. The normalization is done using linear interpolation. For example, for LOS attribute "Pedestrian walking speed", the data obtained for stretch 1 is 1.2 m/s. This value is normalised to 100 and the other stretches' data are interpolated from this value. Similarly, for example, another attribute "Average pedestrian delay" is the delay for a pedestrian to cross the road. It is computed

Table 2 LOS attributes for study stretches

Stretch number	Code	LOS attribute	S1	S2	S3
1	A1	Pedestrian walking speed (m/s)	1.2	1.14	1.11
2	A2	Pedestrian volume (number of pedestrians/hr)	294	564	474
3	A3	Critical gap	2.2	4.6	6
4	A4	Pedestrian crossing time(seconds)	44	34	39
5	A5	Average pedestrian delay (seconds)	20	25	30
6	A6	Continuity of Walking (rating)	1.58	2.15	2.69
7	A7	Walk density	40	30	62
8	A8	Suitability of walk signal time	3.03	2.37	1.9
9	A9	Presence of side walks	Yes	Yes	Yes
10	A10	Presence of zebra crossing	No	Yes	Yes
11	A11	Presence of manned control	No	No	Yes
12	A12	Presence of all red signal at intersections	No	No	No
13	A13	Presence of sign boards	No	Yes	Yes
14	A14	Sidewalk or cross walk surface condition rating	3	2	3
15	A15	Noise level rating	1	1	1
16	A16	Presence of access for disabled	No	No	No
17	A17	Visibility of traffic lights	1	2	1
18	A18	Degree of no of obstacles to pedestrian movement	40	60	70
19	A19	Existence of pedestrian refuge islands	No	No	Yes
20	A20	Maintenance of free walking speeds	2.69	2.24	2.22
21	A21	Pedestrian observance of law	1	1	1
22	A22	Pedestrian satisfaction score	3	3	2
23	A23	Pedestrian area/road area	0.2	0.22	0.3
24	A24	Cross walk width	2	1	1.5
25	A25	Length of pedestrian crossing	20	20	25
26	A26	Continuity of side walks	3	2	1
27	A27	No of lanes	4	4	6
28	A28	Roadway width	24	24	31

Table 2 LOS attributes for study stretches (continued)

Stretch number	Code	LOS attribute	S1	S2	S3
29	A29	Pavement surface condition rating	1	3	3
30	A30	No of access points	8	7	6
31	A31	Presence of bus stops	Yes	Yes	Yes
32	A32	Interference of parking	20	66	45
33	A33	% of fast and heavy moving vehicles	0.0908	0.0832	0.0831
34	A34	Volume	4902	4778	4934
35	A35	Speed	5.7	6.4	5.2
36	A36	Headway	5	3	3
37	A37	Type of land use	Semi residential	Commercial	Commercial
38	A38	Intensity of land use	65	75	88
39	A39	Encroachments	60	70	80
40	A40	Car drivers' observance of law	1	2	2
41	A41	Degree of conflicts with pedestrians	5	7	10

by considering the gap size available for the pedestrian to cross the road as the vehicles pass by. A delay of zero is considered to be 100 and a value of 90 sec is considered to be zero. The average pedestrian delays are converted to a scale of 100 by taking the above limits.

4.4 Determination of weightage factors of LOS characteristics using Saaty scale

An expert opinion survey is adopted to determine the weightage factor of LOS characteristics using Saaty scale. Saaty scale (Saaty, 1980) adopted in Table 3 has been used for the study.

4.4.1 Development of pairwise comparison matrix

A pairwise comparison matrix is developed from the data collected from the experts as per the Saaty scale. The pair wise comparisons are arranged in a square matrix. The diagonal elements of the matrix are 1.

4.4.2 Determination of weights of the characteristics

From the pairwise comparison matrix the weights obtained are given in Table 4. Calculation of consistency index is shown in Table 5.

Consistency index (CI):

$$\mathrm{CI} = \frac{\lambda - 1}{n - 1} = \frac{55.77 - 41}{41 - 1} = 0.369, \tag{1}$$

where n is the number of variables.

Consistency ratio (CR):

$$\begin{aligned} &\text{Consistency index } (\mathrm{CI}) / \text{Random index } (\mathrm{RI}) \\ &= \mathrm{CI}/\mathrm{RI} = 0.369/3.59 = 0.10. \end{aligned} \tag{2}$$

Table 3 Scale of relative importance (According to Saaty (1980))

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over the another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity '*i*' has one of the above nonzero numbers assigned to it when compared with activity '*j*', then *j* has the reciprocal value when compared with *i*.	

Table 4 Weightage factors obtained from pair wise comparison matrix

Stretch number	Code	LOS attribute	Weightage in %
1	A1	Pedestrian walking speed (m/s)	6.74
2	A2	Pedestrian volume	6.25
3	A3	Critical gap	0.72
4	A4	Pedestrian crossing time	5.42
5	A5	Average pedestrian delay	6.31
6	A6	Continuity of walking	0.66
7	A7	Walk density	0.81
8	A8	Suitability of walk signal time	0.60
9	A9	Presence of side walks	5.31
10	A10	Presence of zebra crossing	5.39
11	A11	Presence of manned control	3.14
12	A12	Presence of all red signal at intersections	2.98
13	A13	Presence of sign boards	2.73
14	A14	Sidewalk or cross walk surface condition rating	5.29
15	A15	Noise level rating	0.50
16	A16	Presence of access for disabled	0.46
17	A17	Visibility of traffic lights	3.81
18	A18	Degree of no of obstacles to pedestrian movement	2.05
19	A19	Existence of pedestrian refuge islands	3.45
20	A20	Maintenance of free walking speeds	3.16
21	A21	Pedestrian observance of law	1.07
22	A22	Pedestrian satisfaction score	6.09
23	A23	Pedestrian area/road area	0.76
24	A24	Cross walk width	2.36
25	A25	Length of pedestrian crossing	1.31
26	A26	Continuity of side walks	1.54
27	A27	No of lanes	0.79
28	A28	Roadway width	0.84
29	A29	Pavement surface condition rating	2.73
30	A30	No of access points	1.61
31	A31	Presence of bus stops	1.58
32	A32	Interference of parking	1.50
33	A33	% of fast and heavy moving vehicles	2.10
34	A34	Volume	1.66
35	A35	Speed	1.50
36	A36	Headway	1.58
37	A37	Type of land use	0.99
38	A38	Intensity of land use	0.84
39	A39	Encroachments	1.06
40	A40	Car drivers' observance of law	1.35
41	A41	Degree of conflicts with pedestrians	0.95

Table 5 Determination of consistency indices

Code	LOS attribute	Sum of column weights	Sum of column weights × weightage factor
A1	Pedestrian walking speed (m/s)	11.17	0.75
A2	Pedestrian volume	12.80	0.80
A3	Critical gap	148.67	1.06
A4	Pedestrian crossing time	16.86	0.91
A5	Average pedestrian delay	13.98	0.88
A6	Continuity of walking	158.17	1.04
A7	Walk density	154.17	1.25
A8	Suitability of walk signal time	202.29	1.22
A9	Presence of side walks	23.03	1.22
A10	Presence of zebra crossing	19.03	1.03
A11	Presence of manned control	48.88	1.54
A12	Presence of all red signal at intersections	61.43	1.83
A13	Presence of sign boards	60.59	1.65
A14	Sidewalk or cross walk surface condition rating	34.00	1.80
A15	Noise level rating	174.00	0.87
A16	Presence of access for disabled	177.50	0.82
A17	Visibility of traffic lights	36.01	1.37
A18	Degree of no of obstacles to pedestrian movement	68.03	1.39
A19	Existence of pedestrian refuge islands	30.28	1.04
A20	Maintenance of free walking speeds	61.78	1.95
A21	Pedestrian observance of law	173.82	1.86
A22	Pedestrian satisfaction score	17.10	1.04
A23	Pedestrian area/road area	171.28	1.31
A24	Cross walk width	70.70	1.67
A25	Length of pedestrian crossing	112.20	1.47
A26	Continuity of side walks	102.28	1.58
A27	No of lanes	142.40	1.13
A28	Roadway width	142.85	1.20
A29	Pavement surface condition rating	56.59	1.55
A30	No of access points	118.58	1.91
A31	Presence of buss tops	114.02	1.80
A32	Interference of parking	116.87	1.75
A33	% of fast and heavy moving vehicles	66.96	1.41
A34	Volume	98.40	1.63
A35	Speed	108.40	1.63
A36	Headway	94.50	1.50
A37	Type of land use	139.95	1.39
A38	Intensity of land use	152.25	1.28
A39	Encroachments	133.20	1.42
A40	Car drivers' observance of law	118.62	1.60
A41	Degree of conflicts with pedestrians	130.17	1.24
Total			55.77
Total = Lambda (λ) = 55.77			

Since the consistency ratio is equal to or less than 0.1, the obtained weights are consistent.

4.5 Determination of LOS score using Analytic Hierarchy Process

The generalized equation of AHP is LOS = $\Sigma a_{ij} \times w_j$ where a_{ij} = normalized value and w_j = weightage factor. The normalized value is multiplied with the weightage factor and the sum of the values is the LOS score. The AHP score thus determined is given in Table 6.

The relative normalisation is done in such a way that the best conditions reflect a score near to 100 and the worst condition reflect a score near to zero. The LOS conditions are defined in 5 divisions from A to E which are classified for every 20 divisional scores as shown in Table 7. The score thus determined from the above table is shown in Table 8.

5 Findings of the study

The following are the findings of the analysis:

1. There are 41 attributes that contribute to pedestrian LOS, pedestrian mobility characteristics such as pedestrian walking speed, average pedestrian delay, pedestrian volume and critical gap contribute to more than 25% of the total weightages out of total pedestrian characteristics which contribute to 79% of the total weightage.

Table 6 AHP scores for the study stretches

Stretch number	Stretch name	AHP score
1	NMDC - Falcon	54.93
2	Falcon – Sarojini Devi Hospital	61.28
3	Sarojini hospital - Mehdipatnam Rythu bazaar	66.35

Table 7 Determination of pedestrian LOS from AHP score

Stretch number	AHP score	LOS
1	80–100	A
2	60–80	B
3	40–60	C
4	20–40	D
5	<20	E

Table 8 Pedestrian LOS score

Stretch number	Stretch name	LOS
1	NMDC - Falcon	C
2	Falcon – Sarojini Devi Hospital	B
3	Sarojini hospital - Mehdipatnam Rythu bazaar	B

2. On an average, majority of pedestrian delays of about 84% are contributed due to continuous vehicular traffic.
3. The stretches considered for the study have LOS B and C.
4. This approach considers all the factors and gives a comprehensive view on pedestrian LOS.

6 Recommendations from the study

NMDC to Falcon stretch has been identified as the worst stretch from the analysis that has poor pedestrian facilities and provides poor LOS to the road users. When the functional attributes are observed, the link has very poor level of service which can be improved by the following strategies:

1. Improving the carriage and shoulder width.
2. Improving neighbourhood network characteristics by modifying the geometric characteristics of the surrounding roads.
3. Removing the encroachments on the road improves the capacity of the existing roads.
4. Providing pedestrian raised sidewalks and foot over bridges to improve the level of service.
5. Travel demand management.
6. Positioning of the bus stops.
7. Adopting traffic management strategies to control the traffic.
8. Providing continuous support for pedestrians throughout the stretch by signs, markings, footpaths and crossings
9. Educating road users to follow rules.

7 Conclusions

Pedestrian level of service is influenced by multiple factors that are variable. Multi criteria evaluation and AHP can be used in the determination of pedestrian LOS considering all the factors affecting LOS. Since the road stretches involve dynamic phases with varying behavioural and functional attributes, this study using AHP has proved to be a decision support system for identifying the LOS with capability of different analysers in the system. This approach is a tool for urban transport planners to identify the deficiencies in the corridor and thus evolve a better pedestrian environment. This also helps to understand the existing scenario in a comprehensive way. The study has been generalised in a framework that can be used in any similar conditions. The field data consists of both qualitative and quantitative data for the selected midblock sections. The field

conditions indicate that the pedestrian perceptions, facilities and mobility characteristics are average for the study stretches. Hence the level of service for the study stretches is obtained as B and C. The pedestrian walking speed and pedestrian delay have greater effect on LOS than other variables and an increase in delay reduced the speed and led to poor level of service. It is recommended to reduce the pedestrian delay by improving the underlying conditions which are influenced by the surrounding network characteristics, existing facilities and the road users. These recommendations would change the perceptions of the user as it would increase the convenience and safety.

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