Development of Pedestrian Level of Service (PLOS) model and satisfaction perception rating models for pedestrian infrastructure for mixed land-use urban areas

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Abstract

Existing pedestrian facilities are evaluated using a range of Pedestrian Level of Service (PLOS) assessment models. These models, available for well-defined facilities, consider factors like pedestrian volume and speed, physical infrastructure conditions and perceived satisfaction levels for comfort, safety and security of the facility. The satisfaction level, usually assessed using sample satisfaction survey, is subjective. No comprehensive PLOS assessment model conceptualized in this work is available for old cities having mixed land-use where well-defined pedestrian facilities might not have usually existed. This study eventually identifies relevant PLOS assessment factors for mixed land-use urban areas from literary narratives/previous research works and develops a comprehensive PLOS assessment model for them considering all these factors. The factors were initially grouped into factor groups or parameters using principal component analysis done with importance survey responses from 550 pedestrians from Patna and Gaya, two old cities of India. Six important parameters have been identified namely safety issues under pedestrian traffic interaction; condition of pedestrian infrastructure; pedestrian convenience and sense of security; night time walking; encroachment and walking comfort. The model considers pedestrians' satisfaction for the parameters which is a function of actual conditions for the underlying factors and varies from person to person. To eliminate variability, the study develops pedestrian satisfaction rating models for each parameter through satisfaction survey, correlating existing pedestrian facility condition to perceived satisfaction level, using ordered probit model. Random conditions for each parameter was designed through D-Optimal experimental design considering four levels (best to worst) of factor conditions and survey was done with 780 participants, each participating in 16 experiments.

Keywords Pedestrian Level of Service (PLOS) · Old cities · Perception satisfaction rating models

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Background

Walking forms an integral mode of travel for short distance commuting and for accessing public transport modes. The importance and health benefits of walking in day to day lives of people is well recognized. Proper walking infrastructure and continuous evaluation of the same is essential in cities to enable people to walk safely and comfortably. A wide range of literature is available focusing on assessment of Pedestrian Level of Service (PLOS) for walking infrastructure facilities (Fruin 1971; Khisty 1994; Kadali and Vedagiri 2015; Majumdar and Mitra 2018; Bivina and Parida 2019). Level of service (LOS) of any traffic facility is assessed based on vehicle flow operations considering speed, flow and capacity. Initially, the traffic engineers assessed PLOS using methods similar to LOS assessment methods for traffic facilities i.e. based on pedestrian flow volumes and capacity of the pedestrian facility (Furin 1971; Mori and Tsukaguchi 1987). However, equating human and vehicular flow, without considering qualitative aspects, may not provide a proper assessment of the facility. To resolve this issue, researchers tried to integrate destination accessibility and distance in PLOS assessment framework (Ewing et al. 2013). Further, researchers have used other quantitative factors such as footpath width, shoulder width, buffer zone width and presence of on-street parking for PLOS assessment. Inclusion of qualitative factors to assess level of service offered by pedestrian facilities marked an important advancement in the field of PLOS assessment (Sarkar 1993; Khisty 1994; Parida and Parida 2007). The qualitative factors considered in PLOS assessment included quality of footpath surface, convenience of footpath usage in terms of availability of ramps for accessing elevated footpaths, shades for pedestrians, night time lighting etc. and sense of safety and security perceived by pedestrians. However, each of these factors may influence PLOS in a different way. For example, encroachments like presence of street vendors, although a hindrance for walking, may enhance a sense of security and provide easy shopping options for pedestrians. Thus, different types of encroachment also affect PLOS perception differently and the effect of different types of encroachments has not been studied so far. Table 1 gives a detailed account of both qualitative and quantitative factors, each of which act as either encouragement factor or discouragement factor for walking, considered for PLOS assessment so far in the past works.

Some recent research works considered land-use type for LOS assessment considering land-use type as a categorical variable in the nominal scale (Kadali and Vedagiri 2016; Majumder and Mitra 2018). Land-use type was found to be a variable which significantly affects LOS of pedestrian and bicycle infrastructure facilities (Rani et al. 2018; Majumdar & Mitra 2018). However, the positive or negative effect of a particular land-use type on LOS may not indicate that changing the land-use type will essentially change the LOS of a facility. Also, it may not be feasible to change land-use type with policy interventions for improving LOS of the facility. Land-use in terms of population per unit area or commercial activity per unit area may be a better indicator for predicting LOS. Thus, development of separate PLOS models for different land-use (Indo-HCM 2017; Bivina and Parida 2018) may be a better approach.

Many PLOS assessment models exist for sidewalks and crosswalks and their applications and limitations had been discussed in detail by Kadali and Vedagiri (2015). Lack of consensus in the PLOS assessment outcome for different available PLOS models was discussed by Karatas and Tuydes-Yaman (2018). Also, no single PLOS model systematically consider the contribution of all the factors in deciding the LOS provided by the pedestrian infrastructure. The PLOS assessment models available consider pedestrian perceptions for

Table 1 PLOS assessment factors and their effect on walking

Encouragements for walking			Discouragement for walking		
Factor and Country/Zone	Remarks	References	Factor and Country/Zone	Remarks	References
Buffer Zone USA, India, Brazil, Malaysia, Florida, Brazil, China	Minimum 1.0 m, Absence of buffer zone decreases sense of safety	1; 2; 3; 4; 5; 6; 7; 8; 9	**Unclean Footpath** China, Portugal, India, Brazil, Australia	Restricts footpath space, reduces comfort and attractiveness	6;9;13; 15;16;17; 18;19
Footpath Marking Japan, China, Portugal, Singapore, Malaysia, Brazil	Proper marking and signage enhance safety and comfort	6;7;10; 11;12;13; 14;15;16	**Open Waste Bin** Japan, India, Australia	Restricts footpath space and forces pedestrians to walk on vehicle carriageway	9;10;13; 17;18
Footpath Width Japan, USA, Greece, Portugal, India, Malaysia, Brazil, Australia	Minimum 1.5 m, Lesser width discourages walking	3;6;7;9; 10;13;15; 20;21	**Traffic Volume** Florida, Portugal, India, Brazil, China	High traffic volume affect sense of safety	3;4;6;9; 15;19
Condition of Footpath Surface China, Portugal, Singapore, Malaysia	Better condition attracts pedestrians	4;7;9;14; 15;16;17; 18	**Footpath Height** India	Maximum 15 cm, High footpath reduces accessibility especially for elderly persons	19;22; 23;24
Type of Footpath Surface Malaysia, India, Australia	Properly coloured and even paved surface attracts pedestrians	7;13;17; 18;19;22	**Change in Footpath Height** USA (Florida), Portugal (Lisbon), India, Malaysia, Brazil, China, Australia	Decreases pedestrians' smooth mobility especially for elderly persons and persons with disability	3;4;6; 7;9;13; 15;18
Pedestrian Volume Brazil, Australia, Malaysia	Passive surveillance increases safety perception	6;13;25	**Electric Pole** Japan, Singapore, India, Greece, Portugal, Brazil, China	Limit the space, pedestrian comfort level decreases	4;6;9; 10;14;15; 19;21;26
Roadside Vending Brazil	Enhance safety and security perception	6	**Encroachment (Temporary Vendor)** Asian countries, India	Reduces the clear space of sidewalks, making sidewalks inaccessible or sometimes non-usable even though may sometimes enhance sense of security	9;17;18; 19;26
Sidewalk Maintenance Portugal, Singapore, India, Indonesia	Sidewalk maintenance attract pedestrians	13;14;15; 18;19;27	**Encroachment (Shop Extension)** Asian countries	Reduces the clear space of sidewalks, sidewalks inaccessible or sometimes non-usable	9;19;26
Shade and Trees Greece, Singapore, China, India, Malaysia, Florida, Indonesia	Enhances pedestrians' convenience	2;7;9;14; 16;17;18; 21;27	**Parked Vehicles on Footpath** Asian Countries, Denmark	Forces pedestrians to walk on the carriageway and increases his/her risk	9;19;26

Table 1 (continued)

Encouragements for walking			Discouragement for walking		
Factor and Country/Zone	Remarks	References	Factor and Country/Zone	Remarks	References
Covered Dustbin Greece	Pedestrian can walk on footpath without difficulty as compared to uncovered dustbin	21			
Presence of Access Ramps Greece, Singapore, China, Malaysia	Enhances walking convenience especially for elderly persons and persons with disability	7;14;19; 21;25			
Amenities India, Greece, Malaysia, Brazil	Enhances convenience & attractiveness of pedestrian facility	6;7;9;17; 18;19;26; 21			
Police Patrolling Chicago, India, Brazil	Enhances safety and security perception	6;9;14; 19;28			
CCTV Camera Chicago, Singapore, India, Malaysia	Enhances safety and security perception	9;14;19; 25;28			
Lighting (Night) Greece, China, India, Malaysia, Florida, Brazil, Australia	Enhance safety and security perception, Improves visibility level	2;6;7;9; 13;16;17; 18;21			

Reference Code for Table 1

1. Dixon 1996; 2.Jaskiewicz 2000; 3. Landis et al. 2001; 4.Dandan et al. 2007; 5. Silva & Shah 2010; 6.Florez et al. 2014; 7.Asadi-Shekari Z. et al. 2014; 8. Macdonald et al. 2017; 9. Bivina& Parida 2019; 10.Mori & Tsukaguchi. 1987; 11. Houten et al 2002; 12.Huybers et al 2004; 13. Australian Govt. (DOT), 2011; 14. Koh & Wong 2013; 15. Moura et al 2017; 16. Yang et al. 2019; 17. Krambeck 2006; 18. Juremalani and Chauhan 2017; 19. Rani et al 2018; 20. Ewing et al 2006; 21.Galanis and Eliou 2011; 22. IRC 103, 2012; 23. Indo HCM 2017; 24.Aghaabbasi et. al. 2016; 25. ADB, 2011; 26.Sutikno et al. 2013; 27.Kshisty J, 1994; 28. Jensen 2007

some factors like safety, security and comfort, but the perceptions are subjective. Research on PLOS assessment so far was focused on the assessment of PLOS for well-defined pedestrian facilities. In some cities footpath is not always available as a well-defined accessible elevated path with proper paver blocks. Sometimes the footpath, though available, may not be in usable condition throughout the stretch due to various reasons like broken footpath surface, presence of waste bins, presence of street vendors or even cars or two-wheelers parked on the footpath. Pedestrians are thus compelled to share vehicle carriageway during walking even when they are not crossing the roads and their safety may be compromised. Limited research focuses on the development of comprehensive PLOS model for such facilities (Kadali and Vedagiri 2016). This work attempts to.

1. Develop comprehensive PLOS assessment model for mixed land-use areas of old cities. For the purpose of this study old city refers to "*An urban settlement with narrow roads at many stretches, where proper footpath is not always available, typically built before the advent of motorized vehicles and where scope of widening of road facility for providing proper demarcated footpath is limited. With time, expansions have been made around such settlements with better road infrastructure. The pedestrians encounter a wide range of walking infrastructure conditions from well-defined proper footpaths to inaccessible or no footpath where they are forced to share vehicle carriageway while walking*" The PLOS assessment model uses important factor groups or parameters identified using Principal Component Analysis (PCA) of a comprehensive list of relevant factors from literature. Importance survey of factors identified from literature was conducted at Patna and Gaya, India and this data was used for PCA analysis. Patna, located in North East India on the south bank of river Ganges was founded in 490 BCE. The old settlement, which covered an area having length of 14 kms and width of 2.82 kms, grew over years to its current area of 250 km^2 (35 km long and 16.18 km wide). Latitude and longitude coordinates of Patna are: 25.612677, 85.158875. The city has mixed land-use and the pedestrian infrastructure availability of the city widely varies from no footpaths to well-defined accessible footpaths. Gaya, located 116 km south of Patna, is surrounded by three rocky hills and was built around sixth century BCE. The city of Gaya is similar to the city of Patna in terms of pedestrian infrastructure and has an area of 84.5 km^2. Latitude and longitude coordinates of Gaya are: 24.780010, 84.981827. The proposed PLOS assessment model considers pedestrian satisfaction level for the identified parameters.

2. The scaled satisfaction level or ratings, which depend on the condition of the existing pedestrian infrastructure facility, are random and varies from person to person. Considering the average rating of sample satisfaction perception survey render subjectivity to the PLOS predictions. The study also aims to develop scaled or ordered satisfaction rating prediction models for PLOS assessment parameters using Ordered Probit models. The models relate all possible infrastructure conditions affecting the PLOS factors to satisfaction ratings. All possible infrastructure conditions were obtained through randomised design of experiments.

The next section details the method of selection of important parameters for PLOS assessment. Section Theoretical background–PCA proposes a PLOS assessment model using pedestrians' satisfaction perception of important PLOS parameters identified in Sect. Selection of important PLOS parameters. Section Important parameters for PLOS assessment details the development of satisfaction perception rating prediction models using Ordered Probit model to relate sidewalk condition affecting the PLOS

Table 2 Important parameters for PLOS assessment obtained from PCA

Principle components	Components factors	Abbreviation	Factor loading
Safety from Pedestrian Traffic Interaction (PTI)	Traffic volume and flow	TVF	0.642
	Proper marking of pedestrian way	PMS	0.720
	Buffer zone	BZ	0.569
	Unclean footpath	UF	0.788
	Open waste bin on footpath making it unusable	OWB	0.700
Availability and Condition of Pedestrian Infrastructure (PI)	Footpath width	FW	0.727
	Footpath height	FH	0.697
	Condition of footpath surface	QFS	0.667
	Type of footpath surface	TFS	0.664
	Frequent change of footpath height	CFH	0.625
Pedestrian Convenience and Sense of Security (CS)	Pedestrian volume	PV	0.717
	Roadside vending shops attracting pedestrians	SAP	0.737
	Electric pole etc. causing hindrance to walking	EPH	0.484
	Routine sidewalk maintenance	SM	0.575
	Availability of covered dustbin at regular interval	CD	0.417
Night Time Walking (NW)	Availability of lighting facility at night	LN	0.595
	Regular police patrolling during night	PPN	0.735
	Availability of CCTV cameras to record crime	CCTV	0.659
Encroachment on Footpath (EN)	Encroachments due to temporary vendors	ETV	0.777
	Encroachments due to shop's extension on footpath	EPS	0.778
	Illegally parked vehicles on footpath	IPV	0.655
Pedestrian Walking Comfort (PC)	Shade and trees for pedestrian	ST	0.607
	Ramps to access elevated footpath	RAF	0.801
	Seating facility and drinking water for pedestrians	AMN	0.782

assessment parameters (as illustrated in Table 2) and perceived satisfaction rating. The perceived satisfaction rating survey for each parameter was conducted using a set of randomised conditions. The set of randomised conditions for each parameter was designed through D-Optimal experimental design considering four conditions (best to worst) for underlying factors. The section also presents validation of the satisfaction perception rating models done using 100 random experiments for each model. Section Proposed PLOS model details the illustration and discussion of the proposed PLOS model. Section Modelling perception ratings presents the conclusions of the work.

Selection of important PLOS parameters

The present work aims to develop PLOS assessment model for sidewalks of old cities, having mixed land-use i.e. having residential, commercial or shopping and office activity in the same place. A list of 24 walking encouragement and discouragement factors were identified and elaborated in Table 1. Figure 1 illustrates some of the old city sidewalk conditions (as observed in Patna and Gaya, India) and relates them with the factors detailed in Table 1.

Importance survey for the 24 walking encouragement and discouragement factors identified from literature was conducted in two cities namely Patna and Gaya, India. The survey was conducted by face to face interviews where the surveyors approached the pedestrians on the roadsides and interviewed them. 550 pedestrians were involved in the survey. The pedestrians were asked to rate the importance of each of the 24 factors on a 1 to 5 scale where 1 indicated least important and 5 indicated very important. The factors were explained to the pedestrians in their local language and the surveyors recorded their responses individually. In the survey, the surveyors tried to consider view of pedestrians of all age groups. 17% of the participants were of age less than 19 years; 44% were in the age group of 19 to less than 45 years; 29% were in the age group of 45 to 60 years and 10% were of age more than 60 years. In terms of gender, around 65% were male and 35% were female pedestrians. The sample proportions of different age groups and gender groups were not equal but the sample proportions may be considered as representing the population proportions of pedestrians. PCA was conducted with the importance ratings obtained for the 24 encouragement and discouragement factors to determine the important parameters for PLOS assessment for sidewalks in old cities and their underlying influencing factors. Section Theoretical background–PCA details the theoretical background of PCA. Section Important parameters for PLOS assessment discusses the principal components, which are the PLOS assessment parameters, and their underlying factors which were further used for PLOS model development.

Theoretical background–PCA

PCA reduces dimensionality of data while retaining maximum information. Dimensionality is reduced by finding *'s'* uncorrelated or orthogonal components called *principal components* from *'r'* variables. Here *'s'* is much smaller than *'r'* and the variables are measured n times as vector *X*. PCA successively maximises the variance for the data and obtains *'r'* linear combinations, a_i^T X called principal components. The *[a_i]* vectors are eigenvectors of the covariance matrix corresponding to *'r'* largest eigenvalues. Eigenvalue indicates

Maps showing locations of photographs given below

(A) Encroachment by temporary vendors

(B) Variable footpath width with shop extension encroachment

(C) Footpath with parked vehicle and broken unclean surface

(D) Trees on footpath

(E) Footpath encroached with parked vehicles forcing pedestrians to walk on vehicle carriageway

(F) Footpath with inadequate width forcing pedestrians to share vehicle carriageway

(G) Encroached and broken footpath.

(H) Unclean footpath

(I) Inadequate footpath width with permanent encroachment

Fig. 1 Sidewalk Illustrations from Patna and Gaya, India

the relative importance of each factor in accounting for the particular set of variables being analysed. PCA for 24 identified factors was done using IBM SPSS 16 to obtain the important parameters and their underlying factors for PLOS assessment. Scale reliability of the

data was tested with Cronbach's alpha value which defines the internal consistency that is, how closely related a set of items are as a group. Data suitability for factor loading and sampling adequacy for each variable were tested using Kaiser–Meyer–Olkin (KMO) Test.

Important parameters for PLOS assessment

Six principal components or important parameters were obtained from PCA conducted with importance survey data of 24 walking encouragement and discouragement factors. It could be observed that all the 24 factors were clustered in the six principal components. The six important parameters identified for PLOS assessment were safety issues under pedestrian traffic interaction (PTI), availability and condition of pedestrian infrastructure (PI), pedestrian convenience and sense of security (CS), night time walking (NW), encroachment on footpath (EN) and pedestrian walking comfort (PC). The Cronbach's alpha value was 0.834 which indicates good internal consistency. KMO value of 0.823 indicates that data is adequate for factor loading. Table 2 summarises the important parameters obtained from PCA and their underlying influencing factors.

Proposed PLOS model

The proposed PLOS model indicates the walking condition of sidewalks considering satisfaction perception of pedestrians for all the six important PLOS assessment parameters identified. Initially the overall PLOS score needs to be calculated using perception scores of important PLOS parameters P_{PTI}, P_{PI}, etc. using Eq. 1. The perception scores are perceived satisfaction ratings indicated by pedestrians in 1 to 5 scale, where 1 indicates least satisfactory and 5 indicates extremely satisfactory, of the six important PLOS parameters identified.

$$PLOS_{score} = P_{PTI} + P_{PI} + P_{CS} + P_{NW} + P_{EN} + P_{PC} \tag{1}$$

$PLOS_{score}$ greater than 25 corresponds to PLOS A; 22 –25 corresponds to PLOS B; 18– 21 corresponds to PLOS C; 14 – 17 corresponds to PLOS D; 10– 13 corresponds to PLOS E and below 10 corresponds to PLOS F. Here, PLOS A correspond to best level of service for sidewalks and PLOS F correspond to worst level of service for sidewalks.

Perception ratings are random and depend on sidewalk conditions. Considering average perceptions as scaled perception ratings may lead to subjectivity in PLOS outcome. Therefore, the authors have developed perception rating models for each of the six parameters considering the underlying factors influencing the important PLOS parameters. The next section details the development of perception rating models for the six identified parameters.

Modelling perception ratings

Pedestrians' perceived satisfaction level pertaining to any of the identified PLOS assessment parameter depends on the underlying factors (detailed in Table 2) of the parameter for the candidate sidewalk. For example, the parameter night time walking (NW) was found to be dependent on three factors namely lighting condition (LN),

police patrolling at night (PPN) and availability of CCTV cameras (CCTV). Perception rating of NW will depend on the availability and condition of these factors. The condition of each of the component factors may vary from best to worst, and combination of condition of each component will influence the perception level of the parameter. The condition of each of the component factors of the PLOS parameters are classified in four levels from L1 to L4 where L1 corresponds to the best condition and L4 corresponds to the worst condition. The levels of each component factors were defined and presented in Table 3.

The factors were dummy coded for use in the Ordered Probit Model (Daly et al. 2016). The level 1 of each factor was considered as base level or base variable. For example the dummy coding for LN factor of NW parameter may be written as given in Table 4.

The stated perception ratings of the PLOS assessment parameters were modelled as ordered ratings using Ordered Probit Model. This was done by conducting stated perception rating experiment using randomised combination experiments of combination of different condition levels of component factors. Random combination of different condition levels for each parameter was obtained using Partial Factorial Design. "Design of Randomised Factor Combination Experiment" in Section describes the design of random experiment for obtaining combination of factor conditions. "Modelling Perceptions - Ordered Probit Model" in Section describes the development of perception rating model using Ordered Probit model and "Perception rating models" in Section describes the perception rating model results. "Safety Issues under Pedestrian Traffic Interaction" in Section presents validation of the perception rating models developed.

Design of randomised factor combination experiment

The perception rating experiment for each PLOS assessment parameter was conducted using a combination of levels of each factor using partial D-optimal factorial design. The D-optimality criterion maximises the determinant of the inverse of the variance–covariance matrix in maximum likelihood estimation by minimizing joint confidence sphere around the complete set of estimated model factors. The experimental design software solutions use algorithms to construct D-optimal designs for the smallest possible design that identifies all the necessary combination of factor levels. D-Optimal factorial design for obtaining the main effects of the factors has been widely used in choice modelling experiments (Berger et al. 2000; Kanninen 2002; Jhonson et al. 2013). D-Optimal factorial design of combination levels for satisfaction perception rating experiment of each PLOS assessment parameter was done using IBM SPSS 16. Sixteen combination experiments were obtained from factorial design for each assessment parameter. For example, for assessment parameter NW, one combination experiment may be Lighting Condition as 'Very Few lights' or LN_{L3} (dummy coded as 0 1 0); Police Patrolling at Night as 'Occasional Patrolling' or PPN_{L3} (dummy coded as 0 1 0) and Availability of CCTV cameras as 'Not Available' or $CCTV_{L4}$ (dummy coded as 0 0 1). Satisfaction perception rating survey for the example combination was recorded in 1–5 scale, where 1 indicates not at all satisfactory and 5 indicates very satisfactory.

Satisfaction perception rating survey experiment for sixteen combinations of each of the six PLOS assessment parameters was conducted. 780 participants participated in

Table 3 Detailed description of levels of component factors for PLOS parameters

Condition 1. Safety issues under Pedestrian Traffic Interaction (PTI)

	TVF	PMS	BZ	UF	OWB
L1	Low traffic	Pedestrian marking and sign clearly available	More than 1 m	More than once/day	No open waste bins
L2	Medium traffic but smooth	Pedestrian marking and sign partially available	Between 0.6 m and 1 m	At least once/day	Open bin but cleaned regularly
L3	High traffic but not chaotic (unidirectional flow, lane discipline)	Pedestrian marking and sign faded	Between 0.2 m and 0.6 m	Once a week	Open stinking waste present but footpath partially usable
L4	High traffic but chaotic (illegal cross flow, no lane discipline)	Pedestrian marking and sign not available	Less than 0.2 m	Occasionally	Open stinking waste present and footpath not usable

Condition 2. Availability and Condition of Pedestrian Infrastructure (PI)

	FW	FH	QFS	TFS	CFH
L1	More than 2 m	Less than 5 cm	Walkable	Concrete/Paver Block/Tile Properly Coloured	Less than 2 Changes/km
L2	Between 1.5 m and 2 m	Between 5 and 10 cm	Partially Broken But Walkable	Concrete/Paver Block/Tile Partially Coloured	Between 3 to 5 Changes/km
L3	Between 1 m and 1.5 m	Between 10 and 15 cm	Broken And Not Walkable	Concrete/Paver Block/Tile Faded	Between 6 to 10 Changes/km
L4	Less than 1 m	More than 15 cm	Fully Broken	Concrete/Paver Block/Tile Not Coloured	More than 10 Changes /km

Condition 3. Pedestrian Convenience and Sense of Security (CS)

	PV	SAP	EPH	SM	CD
L1	Very High	More Shops, More People	Less than 20% Encroachment	More than once per day	Adequate
L2	High	Less Shops, More People	20% to 30% Encroachment	At least once a day	Few
L3	Low	More Shops, Less People	30% to 40% Encroachment	Once a week	Very Few
L4	Very Low	Less Shops, Less People	More than 40% Of Encroachment	Occasionally	Not Present

Table 3 (continued)

4. Night Time Walking (NW)

Condition	LN	PPN	CCTV
L1	Lighting all along the way	Regular	Adequate
L2	Most places having lights	Sometime	Few
L3	Very Few lights	Occasionally	Very Few
L4	No lighting	No Patrolling	Not Present

5. Encroachment on Footpath (EN)

Condition	ETV	EPS	IPV
L1	Less than 20% encroachment	Less than 20% encroachment	Less than 20% encroachment
L2	20% to 30% encroachment	20% to 30% encroachment	20% to 30% encroachment
L3	30% to 40% encroachment	30% to 40% encroachment	30% to 40% encroachment
L4	More than 40% encroachment	More than 40% encroachment	More than 40% encroachment

6. Pedestrian Walking Comfort (PC)

Condition	ST	RAF	AMN
L1	More than 80% coverage	Available at every change	Adequate
L2	80% to 60% coverage	Available at few changes	Few
L3	60% to 40% coverage	Available at very few changes	Very few
L4	Less than 40% coverage	Not Available	Not present

Table 4 Example of variable dummy coding for model

Factor	Variable coding			Field situation (from table 3)
LN_{L1}	0	0	0	Lighting all along the way (Base Variable)
LN_{L2}	1	0	0	Most places having lights
LN_{L3}	0	1	0	Very Few lights
LN_{L4}	0	0	1	No lighting

the survey and each participant was given 16 random experiment combinations to rate each combination on 1–5 scale. Of these 780 participants, 13% were of age less than 19 years; 53% were of age group of 19 to less than 45 years; 22% were in age group of 45 to 60 years and 12% of age more than 60 years. Among the 780 participants, 68% were male and 32% were female. The satisfaction perception rating survey was conducted as roadside interview survey. Section Modelling perceptions–ordered probit model details the development of perception rating model using Ordered Probit model.

Modelling perceptions–ordered probit model

The ordered perceptions for PLOS assessment parameters were modelled using Ordered Probit model which considers the ordered nature of the responses. Ordered Probit model was used for modelling dependent variable $YP_{Parameter}$, i.e. perception rating response (recorded in 1–5 scale) as a function of different levels of component factors X, considered as dummy categorical variables, of the PLOS parameter. The model may be specified as shown in Eq. 2.

$$YP_{Parameter} = \beta X \varepsilon \tag{2}$$

In the above equation, the β vector is a vector of estimable parameters, and ε is the normally distributed random error (Washington et al. 2011). The perception rating model was calibrated for the PLOS parameter using the perception experiment data using Maximum Likelihood Estimate to obtain $β$ vector and the thresholds $\mu_1, \mu_2 \& \mu_3$. The perception rating for any parameter or combination of factor levels, $P_{parameter}$, can be obtained using Eq. 3.

$$P_{parameter} = \begin{cases} 1 & YP_{Parameter} \leq 0 \\ 2, & 0 < YP_{Parameter} \leq \mu_1 \\ 3, & \mu_1 < YP_{Parameter} \leq \mu_2 \\ 4, & \mu_2 < YP_{Parameter} \leq \mu_3 \\ 5, & YP_{Parameter} > \mu_3 \end{cases} \tag{3}$$

The goodness of fit of the logistic regression model may be assessed using the adjusted ρ^2 statistic which may be estimated using Eq. 4.

$$\rho^2 = 1 - \frac{L(\beta) - k}{L(0)} \tag{4}$$

Table 5 Ordered model output

1. Safety issues under Pedestrian Traffic Interaction (PTI)		2. Availability and condition of pedestrian infrastructure (PI)		3. Pedestrian convenience and sense of security (CS)		4. Night time walking (NW)		5. Encroachment on foot-path (EN)		6. Pedestrian walking comfort (PC)	
Factor	Coefficient	Factor	Coefficient	Factor	Coefficient	Factor	Coefficient	Factor	Coefficient	Factor	Coefficient
Constant	4.668*	Constant	4.941*	Constant	12.500*	Constant	5.929*	Constant	4.9798*	Constant	5.616*
TVF_{L1}	Base Variable	FW_{L1}	Base Variable	PV_{L1}	Base Variable	LN_{L1}	Base Variable	ETV_{L1}	Base Variable	ST_{L1}	Base Variable
TVF_{L2}	−0.998*	FW_{L2}	−0.954*	PV_{L2}	−4.555*	LN_{L2}	−0.150**	ETV_{L2}	−0.180**	ST_{L2}	−0.438*
TVF_{L3}	−1.239*	FW_{L3}	−1.306*	PV_{L3}	−5.093*	LN_{L3}	−0.814*	ETV_{L3}	−0.759*	ST_{L3}	−1.142*
TVF_{L4}	−2.252*	FW_{L4}	−2.104*	PV_{L4}	−6.579*	LN_{L4}	−2.083*	ETV_{L4}	−1.870*	ST_{L4}	−2.681*
PMS_{L1}	Base Variable	FH_{L1}	Base Variable	SAP_{L1}	Base Variable	PPN_{L1}	Base Variable	EPS_{L1}	Base Variable	RAF_{L1}	Base Variable
PMS_{L2}	−0.088	FH_{L2}	−0.290*	SAP_{L2}	−0.272**	PPN_{L2}	−1.293*	EPS_{L2}	−1.178*	RAF_{L2}	−1.630*
PMS_{L3}	−0.772*	FH_{L3}	−0.636*	SAP_{L3}	−2.582*	PPN_{L3}	−0.596*	EPS_{L3}	−0.568*	RAF_{L3}	−0.825*
PMS_{L4}	−0.855*	FH_{L4}	−0.589*	SAP_{L4}	−3.173*	PPN_{L4}	−2.076*	EPS_{L4}	−1.871*	RAF_{L4}	−2.674*
BZ_{L1}	Base Variable	QFS_{L1}	Base Variable	EPH_{L1}	Base Variable	$CCTV_{L1}$	Base Variable	IPV_{L1}	Base Variable	AMN_{L1}	Base Variable
BZ_{L2}	−0.213**	QFS_{L2}	−0.298**	EPH_{L2}	0.309**	$CCTV_{L2}$	−0.708*	IPV_{L2}	−0.706*	AMN_{L2}	−1.088*
BZ_{L3}	−0.470*	QFS_{L3}	−0.570*	EPH_{L3}	−1.837*	$CCTV_{L3}$	−1.024*	IPV_{L3}	−0.940*	AMN_{L3}	−1.471*
BZ_{L4}	−0.571*	QFS_{L4}	−0.880*	EPH_{L4}	−1.946*	$CCTV_{L4}$	−1.860*	IPV_{L4}	−1.672*	AMN_{L4}	−2.418*
UF_{L1}	Base Variable	TFS_{L1}	Base Variable	SM_{L1}	Base Variable	μ_1	1.791*	μ_1	1.406*	μ_1	1.521*
UF_{L2}	−0.266**	TFS_{L2}	−0.193**	SM_{L2}	−0.241**	μ_2	3.087*	μ_2	2.629*	μ_2	3.434*
UF_{L3}	−1.288*	TFS_{L3}	−0.973*	SM_{L3}	−3.590*	μ_3	4.728*	μ_3	4.061*	μ_3	5.176*
UF_{L4}	−1.011*	TFS_{L4}	−0.870*	SM_{L4}	−2.7470*	ρ^2	0.304	ρ^2	0.255	ρ^2	0.396
OWB_{L1}	Base Variable	CFH_{L1}	Base Variable	CD_{L1}	Base Variable						
OWB_{L2}	−0.140	CFH_{L2}	−0.202**	CD_{L2}	−0.983*						
OWB_{L3}	−0.507*	CFH_{L3}	−0.605*	CD_{L3}	−2.430*						
OWB_{L4}	−0.718*	CFH_{L4}	−0.557*	CD_{L4}	−2.654*						
μ_1	1.913*	μ_1	1.897*	μ_1	2.244*						
μ_2	3.432*	μ_2	3.110*	μ_2	9.423*						
μ_3	4.846*	μ_3	4.798*	μ_3	12.651*						

Table 5 (continued)

1. Safety issues under Pedestrian Traffic Interaction (PTI)		2. Availability and condition of pedestrian infrastructure (PI)		3. Pedestrian convenience and sense of security (CS)		4. Night time walking (NW)		5. Encroachment on foot-path (EN)		6. Pedestrian walking comfort (PC)	
Factor	Coefficient	Factor	Coefficient	Factor	Coefficient	Factor	Coefficient	Factor	Coefficient	Factor	Coefficient
ρ^2	0.231	ρ^2	0.199	ρ^2	0.375						

Variables significant at $P=0$*; $P<0.05$**

Here L(0) is the value of the log-likelihood function when all parameters are zero, L(β) is the value of the log likelihood function at its maximum and k is the degree of freedom. PLOS models were developed considering the best level (L1) as the base level of dummy variable.

Perception rating models

Perception rating prediction models were calibrated with the perception survey data using LIMDEP 5.0. The perception rating models for all the six PLOS assessment parameters are presented in Table 5.

The perception rating models for PLOS assessment parameters relate perception rating outcomes to the condition of various aspects of the candidate sidewalk. The guidelines for assessment of various aspects of sidewalk facility through survey of the facility can be obtained from Table 3. The perception ratings for each PLOS assessment parameter can be estimated using the calibrated perception rating model and survey of various aspects of the sidewalk facility for which PLOS needs to be assessed.

The contribution of condition of various factors on perception levels of individual PLOS assessment parameters were studied in detail to obtain insight of pedestrians expectations on various aspects of the sidewalk facility. The subsequent subsections present detailed assessment of each PLOS assessment parameter and their influencing factors.

Safety issues under pedestrian traffic interaction

The safety issue under Pedestrian Traffic Interaction (PTI) depends on Traffic Volume and Flow (TVF), Pavement Marking and Signs (PMS), Buffer Zone (BZ), Unclean Footpath (UF) and Open Waste Bins (OWB). UF and OWB discourages pedestrians and they are forced to walk close to vehicle carriageway or share vehicle carriageway while walking. The satisfaction perception of pedestrians for safety issue under PTI or P_{PTI} may be obtained from Table 5 or Eqs. 5 and 6.

$$
\begin{aligned}
YP_{PTI} = {} & 4.67 - 0.99TVF_{L2} - 1.24TVF_{L3} - 2.25TVF_{L4} - 0.09PMS_{L2} \\
& - 0.78PMS_{L3} - 0.86PMS_{L4} - 0.21BZ_{L2} - 0.47BZ_{L3} - 0.57BZ_{L4} \\
& - 0.27UF_{L2} - 1.29UF_{L3} - 1.01UF_{L4} - 0.14OWB_{L2} - 0.51UF_{L3} - 0.72UF_{L4} + \varepsilon
\end{aligned}
$$
(5)

$$
P_{PTI} = \begin{cases}
1, & YP_{PTI} \le 0 \\
2, & 0 < YP_{PTI} \le 1.91 \\
3, & 1.91 < YP_{PTI} \le 3.43 \\
4, & 3.43 < YP_{PTI} \le 4.85 \\
5, & YP_{PTI} > 4.85
\end{cases}
$$
(6)

For example, the perception for safety issues under pedestrian traffic interaction, YP_{PTI}, if traffic volume and flow in the carriageway (TVF) is at L_2 condition (i.e. TVF is 1 0 0 or, TVF_{L2} is 1, TVF_{L3} is 0 and TVF_{L4} is 0); PMS is at L_4 condition (i.e. 0 0 1); BZ is at L_3 condition (i.e. 0 1 0); UF is at L_1 condition (i.e. 0 0 0) and OWB is at L_2 condition (i.e. 1 0 0) may be written as Eq. 7.

Table 6 Safety issues under Pedestrian Traffic Interaction (PTI)

Variable	P1 (Extremely unsatisfied)	P2 (Unsatisfied)	P3 (Acceptable)	P4 (Satisfied)	P5 (Very Satisfied)
TVF – L2	0.1118	0.257	–0.2827	–0.0829	–0.0032
TVF – L3	0.1559	0.2856	–0.3405	–0.0971	–0.0039
TVF – L4	0.416	0.2443	–0.4988	–0.1533	–0.0082
PMS – L2	0.0062	0.029	–0.0249	–0.0099	–0.0004
PMS – L3	0.0771	0.2164	–0.2226	–0.0683	–0.0026
PMS – L4	0.0891	0.2328	–0.2453	–0.0738	–0.0028
BZ – L2	0.0161	0.0688	–0.0611	–0.0228	–0.0009
BZ – L3	0.0402	0.1437	–0.1364	–0.0458	–0.0018
BZ – L4	0.0515	0.1703	–0.1659	–0.0538	–0.0021
UF – L2	0.02	0.0858	–0.076	–0.0286	–0.0012
UF – L3	0.1847	0.2584	–0.3523	–0.0876	–0.0032
UF – L4	0.1141	0.259	–0.2861	–0.0837	–0.0033
OWB – L2	0.0102	0.0458	–0.04	–0.0154	–0.0006
OWB – L3	0.0443	0.1538	–0.1474	–0.0488	–0.0019
OWB – L4	0.0699	0.205	–0.2078	–0.0646	–0.0025

$$YP_{PTI} = 4.67 - 0.99 \times 1 - 0.86 \times 1 - 0.47 \times 1 - 0.14 \times 1 + \varepsilon \tag{7}$$

The perception rating P_{PTI} for the above example condition may be obtained by comparing YP_{PTI} values with the µ values for PTI model in Table 5 and Eq. 4 or from the scale provided in Eq. 6.

Marginal effects for the dummy variables were calculated for the PLOS perception prediction models. Marginal effects show the change in probability of different outcomes i.e. the perception ratings with the change of levels of dummy variables compared to the base variable. The marginal effects for perception rating or probability of change of perception rating of PTI for change in levels of TVF, PMS, BZ, UF and OWB from best (L1) to good (L2); acceptable (L3) and worst (L4) was calculated and is presented in Table 6.

From Table 6 it may be observed that the change in factor levels of TVF, PMS, BZ, UF and OWB affect the perception rating level significantly. Table 6 shows that the satisfaction level of TVF is more sensitive to traffic flow condition (smooth or chaotic) compared to traffic volume when pedestrians walk close to carriageway. The probability of pedestrians being unsatisfied (i.e. having perception level 1) increases by 41.6% when low volume smooth traffic changes to high volume chaotic traffic whereas same probability decreases by 25% when the change is to high traffic volume and non-chaotic flow. It can be observed that satisfaction perception level is not much sensitive to change in conditions of PMS or BZ. Past studies indicate significant improvement in satisfaction and safety perception of pedestrians with adequate pavement marking and buffer zone area (Dixon 1996; Houten et al. 2002). The difference in result may be because in mixed land-use areas of old cities, properly marked pedestrian sidewalk with buffer from traffic is rare and therefore, pedestrians may not perceive the importance of marking and buffer zone for sidewalks. The satisfaction level rating was found to be sensitive to usability of available pedestrian infrastructure as rating was observed to improve with regular cleaning of footpath and removal of open waste bin from the footpath.

Table 7 Availability and condition of pedestrian infrastructure (PI)

Variables	P1 (Extremely unsatisfied)	P2 (Unsatisfied)	P3 (Acceptable)	P4 (Satisfied)	P5 (Very satisfied)
FW – L2	0.0578	0.3073	–0.159	–0.1967	–0.0095
FW – L3	0.0996	0.3865	–0.2267	–0.2471	–0.0124
FW – L4	0.2531	0.4454	–0.3425	–0.3353	–0.0207
FH – L2	0.0113	0.1	–0.0376	–0.0701	–0.0036
FH – L3	0.0311	0.2147	–0.0972	–0.1418	–0.0069
FH – L4	0.0279	0.1996	–0.0883	–0.1327	–0.0065
QFS– L2	0.0117	0.1026	–0.0388	–0.0718	–0.0037
QFS– L3	0.0267	0.1936	–0.0849	–0.1291	–0.0063
QFS – L4	0.0507	0.2873	–0.1444	–0.1848	–0.0089
TFS – L2	0.0069	0.0666	–0.0227	–0.0481	–0.0026
TFS – L3	0.0666	0.3065	–0.177	–0.1879	–0.0082
TFS – L4	0.0498	0.2843	–0.1422	–0.183	–0.0088
CFH – L2	0.0075	0.0698	–0.0248	–0.0498	–0.0027
CFH– L3	0.029	0.2047	–0.0912	–0.1358	–0.0066
CFH– L4	0.0259	0.1894	–0.0825	–0.1265	–0.0062

Availability and condition of pedestrian infrastructure

Availability and Condition of Pedestrian Infrastructure (PI) was found to be an important PLOS assessment parameter. Important factors identified for measurement of PI were Footpath Width (FW), Footpath Height (FH), Quality of Footpath Surface (QFS), Type of Footpath Surface (TFS) and Change in Footpath Height (CFH), as defined in Table 2. The marginal effects for satisfaction rating of PI for change in levels of FW, FH, QFS, TFS and CFH from best (L1) to good (L2); acceptable (L3) and worst (L4) were calculated and is presented in Table 7. For example, FH of 5 cm is considered as the best condition of availability of elevated footpath, but when footpath height increases, the condition worsens due to accessibility issue.

It may be observed from Table 7 that FW is an important parameter and probability of being extremely unsatisfied (P1) and unsatisfied (P2) increases by 25.3% and 44.5% respectively when footpath width becomes lower than 1.5 m. Literature also suggests that footpath width is an important parameter in PLOS assessment (Raad, 2018). As footpaths are not provided with ramps, increase of footpath height increases chance of perceived dissatisfaction. Frequency of change in footpath height (CFH) also decreases satisfaction. The impact of QFS and TFS condition does not cause extreme dissatisfaction to pedestrians.

Pedestrian convenience and sense of security

Convenience and sense of security (CS) provided by pedestrian infrastructure facility, an important parameter, had been widely used in PLOS assessment. The factors perceived to be important in assessing satisfaction level for pedestrian convenience and sense of security are pedestrian volume (PV), roadside shops attracting pedestrians (SAP), electric poles, trees etc. causing hindrance to walking (EPH), sidewalk maintenance (SM), and availability of covered dustbins at regular intervals (CD). Table 8 presents the marginal effects for

Table 8 Pedestrian convenience and sense of security (CS)

Variables	P1 (Extremely unsatisfied)	P2 (Unsatisfied)	P3 (Acceptable)	P4 (Satisfied)	P5 (Very satisfied)
PV – L2	0.6177	0.3546	–0.9724	0	0
PV – L3	0.7588	0.2236	–0.9825	0	0
PV – L4	0.9654	0.0287	–0.9941	0	0
SAP – L2	0.0011	0.0772	–0.0783	0	0
SAP – L3	0.1188	0.673	–0.7918	0	0
SAP – L4	0.2305	0.6558	–0.8863	0	0
EPH – L2	–0.0008	–0.0778	0.0786	0	0
EPH – L3	0.0408	0.561	–0.6018	0	0
EPH – L4	0.0485	0.5857	–0.6342	0	0
SM – L2	0.0009	0.0673	–0.0682	0	0
SM – L3	0.4204	0.498	–0.9184	0	0
SM – L4	0.1452	0.6778	–0.8231	0	0
CD – L2	0.0083	0.3062	–0.3145	0	0
CD – L3	0.0975	0.6618	–0.7593	0	0
CD – L4	0.1298	0.676	–0.8059	0	0

satisfaction rating of CS for change in conditions of PV, SAP, EPH, SM and CD from best (L1) to good (L2), acceptable (L3) and worst (L4).

It may be observed from Table 8 that satisfaction levels of satisfied (P4) and very satisfied (P5) were not sensitive to change of pedestrian facility condition. This can be due to the fact that the scale interval of satisfaction perception level P3 is large (ranging from 2.2–9.42) and shift in satisfaction perception from P3 to P4 will require significant change in condition of the factors. The available pedestrian facility for mixed land-use areas of old cities usually have many shops, very few covered dustbins and generally have electric poles at the middle of the footpath causing hindrance to walking. In this situation, pedestrians cannot perceive the best condition and provide a satisfaction level of acceptable (P3) or below in most conditions. Also it may be observed that the satisfaction rating is most sensitive to PV and as PV decreases the dissatisfaction increases rapidly. High pedestrian volume provides a sense of security to the users. This reconfirms the findings from past work (Mackett 2001).

Night time walking

Night time walking (NW) condition provided by pedestrian facility is an important parameter for PLOS assessment. Satisfaction rating of NW conditions depend on lighting facility (LN), police patrolling (PPN) and availability of video surveillance facilities or CCTV cameras (CCTV). Table 9 presents the marginal effects for perception rating or probability of change of perception rating of NW for change in availability conditions of LN, PPN and CCTV from best (L1) to good (L2); acceptable (L3) and worst (L4).

It may be observed from Table 9 that perception of satisfaction level was more sensitive to availability and frequency of CCTV cameras focussing to keep constant surveillance on sidewalk compared to PPN. LN condition was also an important parameter and satisfaction level assessment was very sensitive to LN for night time walking condition.

Table 9 Night time walking (NW)

Variables	P1 (Extremely unsatisfied)	P2 (Unsatisfied)	P3 (Acceptable)	P4 (Satisfied)	P5 (Very satisfied)
LN – L2	0.0003	0.0208	0.0383	–0.0395	–0.0199
LN – L3	0.0036	0.1416	0.1708	–0.2295	–0.0865
LN – L4	0.0431	0.4651	0.1682	–0.5016	–0.1748
PPN – L2	0.0104	0.2576	0.2106	–0.3565	–0.122
PPN – L3	0.002	0.0966	0.1358	–0.1668	–0.0677
PPN – L4	0.0427	0.4636	0.1689	–0.5008	–0.1744
CCTV – L2	0.0027	0.1192	0.1551	–0.1993	–0.0777
CCTV– L3	0.0058	0.1899	0.1948	–0.2878	–0.1028
CCTV – L4	0.0298	0.4088	0.1912	–0.4699	–0.1599

Encroachment on footpath

Footpath encroachment (EN) is commonly observed in old cities having mixed land-use. EN had been identified as an important PLOS assessment parameter at many places (Krambeck 2006; Jensen 2007; Juremalani and Chauhan 2017). The effect of type of encroachment on satisfaction rating of sidewalks has not been studied so far. In this work, effect of type of encroachment on satisfaction perception of pedestrian facility was studied. EN can be due to vendors (ETV), shop extensions displaying goods on footpaths (EPS) or due to illegally parked vehicles on the footpath (IPV). The effect of the proportion of footpath encroached by vendors, shop extensions and parked vehicles on satisfaction level was studied by developing satisfaction rating model presented in Table 5. Table 10 presents the marginal effects for satisfaction rating of EN for change in conditions of ETV, EPS and IPV from best (L1) to good (L2), acceptable (L3) and worst (L4).

It can be observed that encroachment due to effect of shop extension causes greater discomfort to pedestrians compared to illegally parked vehicles or street vendors for the same level of partial encroachment.

Table 10 Encroachment on Footpath (EN)

Variables	P1 (Extremely unsatisfied)	P2 (Unsatisfied)	P3 (Acceptable)	P4 (Satisfied)	P5 (Very satisfied)
ETV–L2	0.0032	0.0365	0.0316	–0.0501	–0.0212
ETV–L3	0.0211	0.1719	0.0921	–0.2116	–0.0735
ETV–L4	0.1259	0.425	0.0292	–0.4353	–0.1449
EPS–L2	0.0463	0.278	0.0922	–0.3142	–0.1023
EPS–L3	0.0135	0.1248	0.0797	–0.1597	–0.0584
EPS–L4	0.126	0.425	0.0292	–0.4353	–0.1449
IPV–L2	0.0188	0.1589	0.0895	–0.1976	–0.0695
IPV–L3	0.0303	0.2178	0.0966	–0.2582	–0.0865
IPV–L4	0.0973	0.3898	0.0527	–0.4071	–0.1328

Table 11 Pedestrian walking comfort (PC)

Variables	P1 (Extremely unsatisfied)	P2 (Unsatisfied)	P3 (Acceptable)	P4 (Satisfied)	P5 (Very satisfied)
ST–L2	0.0286	0.1322	–0.1052	–0.0547	–0.0009
ST–L3	0.1111	0.312	–0.3046	–0.1165	–0.002
ST–L4	0.4915	0.3224	–0.5847	–0.2227	–0.0065
RAF–L2	0.2042	0.379	–0.4294	–0.1507	–0.003
RAF–L3	0.0672	0.2402	–0.2143	–0.0915	–0.0015
RAF–L4	0.4893	0.3235	–0.5841	–0.2222	–0.0065
AMN–L2	0.1028	0.3012	–0.2895	–0.1125	–0.0019
AMN–L3	0.1704	0.3638	–0.3917	–0.1399	–0.0027
AMN–L4	0.4125	0.3585	–0.5615	–0.204	–0.0054

Pedestrian walking comfort

Pedestrian walking comfort (PC) level and satisfaction for comfort level had been widely used as an important PLOS assessment parameter in PLOS literature (Asadi-Shekari et al. 2014; Rani et al 2018; Yang et al. 2019). Satisfaction level for PC while walking was found to be dependent on the availability of shades and trees along footpath (ST), availability of access ramps to elevated footpath (RAF) and availability of seating facility and drinking water (AMN) at convenient intervals. Table 11 presents the marginal effects for perception rating or probability of change of perception rating of PC for change in conditions of ST, RAF and AMN from best (L1) to good (L2), acceptable (L3) and worst (L4).

It can be observed that all the identified comfort parameters affect the satisfaction rating of PC significantly.

Perception rating model validation

The perception rating models were validated by comparing actual and predicted perception ratings for 100 perception rating experiments for each model. Table 12 presents the actual and predicted satisfaction rating outcomes.

It may be observed from the comparison of predicted and actual satisfaction ratings that the predicted ratings from the models developed and actual satisfaction ratings show significant similarity for all models.

Proposed PLOS model–illustration and discussion

The proposed PLOS model takes into consideration user's satisfaction level for all the relevant pedestrian infrastructure related factors which affect walkability of sidewalks and their relative importance through perception rating models. In an attempt to illustrate the use of the proposed PLOS assessment model, five locations of Patna, India namely Bailey road, Boring road, Kankarbagh road, Ashok Rajpath and Rajendra Nagar, having widely varying sidewalk conditions, were selected and attempt was made to assess their PLOS using the proposed model. The locations were surveyed to get the details of the sidewalk conditions related to the identified PLOS assessment parameters

Table 12 Validation of perception model

Principle components	Actual perception	Predicted perception				
		1	2	3	4	5
Safety issues under Pedestrian Traffic Interaction (PTI)	1	0	5	0	0	0
	2	0	33	18	0	0
	3	0	8	24	0	0
	4	0	0	0	6	3
	5	0	0	0	0	3
Availability and Condition of Pedestrian Infrastructure (PI)	1	0	3	0	0	0
	2	0	19	23	0	0
	3	0	2	39	1	0
	4	0	0	1	5	3
	5	0	0	0	0	4
Pedestrian Convenience and Sense of Security (CS)	1	0	5	0	0	0
	2	0	31	7	0	0
	3	0	4	40	0	0
	4	0	0	0	6	4
	5	0	0	0	0	3
Night time Walking (NW)	1	0	0	0	0	0
	2	0	7	3	1	0
	3	0	4	8	10	0
	4	0	1	9	33	1
	5	0	0	0	11	12
Encroachment on Footpath (EN)	1	0	10	6	0	0
	2	0	2	9	10	0
	3	0	0	5	38	2
	4	0	0	0	7	5
	5	0	0	0	0	6
Pedestrian Walking Comfort (PC)	1	7	3	1	0	0
	2	4	8	10	0	0
	3	1	8	34	1	0
	4	0	0	11	6	1
	5	0	0	0	0	5

namely safety issues under pedestrian traffic interaction, availability and condition of pedestrian infrastructure, pedestrian convenience and sense of security, night time walking conditions, encroachment on footpath and pedestrian walking comfort. For recording details of condition of each PLOS assessment parameter, the condition of their underlying factors were recorded in a scale of best to worst following the guidelines proposed in Table 3. For example, for recording condition of '*availability and condition of pedestrian infrastructure*', footpath width, footpath height, condition of footpath surface, type of footpath surface and change in footpath height per km observed were recorded. If the footpath width was more than 2 m, the condition of footpath width was recorded as L1 or best condition and if there were more than 10 height changes per km, the footpath height change was recorded as L4 or worst condition. Then using the inputs

	PLOS Description	Perception Score		PLOS Level
(A) Example PLOS:A Bailey Road	Continuous footpath of width >2m. Wide buffer zone used for vehicle parking. Height change <2 per km. Clean good surface. Regular police patrolling makes the sidewalk safe. No major encroachment or hindrance observed apart from a few poles. Convenience amenities like seating facility also observed at few points.	P_{PTI} P_{PI} P_{CS} P_{NW} P_{EN} P_{PC} **TOTAL**	4 5 4 5 4 4 **26**	A
(B) Example PLOS:B Kankarbagh Road	Continuous footpath of width >2m with 3 to 5 height changes per km. Buffer zone width <0.6m. Clean footpath with good surface. Regular police patrolling makes the sidewalk safe. Partial encroachment with vendor.	P_{PTI} P_{PI} P_{CS} P_{NW} P_{EN} P_{PC} **TOTAL**	3 5 3 4 4 3 **22**	B
(C) Example PLOS:C Rajendra Nagar	Sidewalk width between 1.5m and 2m. No buffer observed. Encroachment observed at many places. Height change between 6 to 10 per km. Night time walking is safe as there are number of shops and pedestrian volume is high.	P_{PTI} P_{PI} P_{CS} P_{NW} P_{EN} P_{PC} **TOTAL**	2 3 1 4 4 4 **18**	C
(D) Example PLOS:D Boring Road	Footpath between 1.5m – 2m wide with no buffer zone. Heavy encroachment observed, occasionally forcing pedestrians to share vehicle carriageway. Since pedestrian volume is high it is safe for night time walking. Footpath is not cleaned or maintained regularly.	P_{PTI} P_{PI} P_{CS} P_{NW} P_{EN} P_{PC} **TOTAL**	2 3 2 4 2 3 **16**	D
(E) Example PLOS:E Ashok Rajpath	Footpath width <1.5 m with heavily broken and unclean surface making the facility unusable at many places and forcing pedestrians to walk on vehicle carriageway. Heavy encroachment present. No CCTV cameras or police patrolling makes night walking unsafe.	P_{PTI} P_{PI} P_{CS} P_{NW} P_{EN} P_{PC} **TOTAL**	1 2 2 2 2 1 **10**	E

Fig. 2 PLOS assessment illustrations

from survey and proposed satisfaction rating models detailed in Table 5, the satisfaction ratings for the six identified PLOS assessment parameters i.e. P_{PTI}, P_{PI}, P_{CS}, P_{NW}, P_{EN} and P_{PC} were determined. The perception score and PLOS outcome were then estimated from the proposed PLOS model detailed in Sect. 3. The five locations surveyed had PLOS outcomes of A, B, C, D and E and Fig. 2 gives a detailed account of the pedestrian facilities of these locations.

Conclusions

In this work, a PLOS assessment model for sidewalks was developed for mixed land-use areas of old cities. A conceptual definition of old city was developed for this study. Level of service indicates pedestrians' satisfaction level with the available walking infrastructure in the city. Pedestrians' satisfaction level depends on various sidewalk-related factors, which can be broadly classified as encouragement factors and discouragement factors for walking. Initially, 24 encouragement and discouragement factors relevant for walking condition assessment of sidewalks had been identified from literature. The importance assigned to these factors by pedestrians regularly using the sidewalks of typical old city, as conceptualized for this study, was recorded through survey. The importance assigned to these 24 factors were recorded in a scale of $1 - 5$ where 1 indicates least important and 5 indicates very important and 550 pedestrians from Patna and Gaya, India participated in the survey. With these importance ratings, six important PLOS assessment parameters and their underlying influencing factors were identified using PCA. The six important PLOS assessment parameters identified were safety issues under pedestrian traffic interaction (PTI), availability and condition of pedestrian infrastructure (PI), pedestrian convenience and sense of security (CS), night time walking (NW), encroachment on footpath (EN) and pedestrian walking comfort (PC). PTI included traffic volume and flow condition, footpath markings, presence of buffer zone, cleanliness of footpath and presence of open waste bin on footpath. PI included footpath height, width, surface type and condition and change of footpath height per kilometre. CS included pedestrian volume, roadside vendors attracting pedestrians, presence of electric poles causing hindrance to walking, sidewalk maintenance and availability of covered waste bins at regular intervals. NW included factors like night time lighting of footpath, availability of CCTV and police patrolling. EN included encroachment by temporary vendors, shop extensions on footpath and illegally parked vehicles on footpath. PC included presence of shades for pedestrians, availability of seating facility and drinking water and presence of access ramps for elevated footpaths. The proposed PLOS model considers pedestrians' perception for these six identified parameters in a scale of $1 - 5$ where 1 indicates least satisfactory and 5 indicates extremely satisfactory.

The satisfaction rating of a given footpath any pedestrian is expected to provide for any parameter depends on the condition of the sidewalk pertaining to the parameter. The condition of the sidewalk pertaining to any parameter depends on the condition of underlying factors which were obtained from PCA. The usual practice for obtaining pedestrians' perception for PLOS assessment parameters is through satisfaction survey that involves a great deal of survey effort. Moreover, the PLOS outcome depends on the sample of pedestrians surveyed and no clear guideline is provided to the surveyors for doing the survey of pedestrian population. The unique feature of the present work is the calibration of satisfaction rating scales for all the identified PLOS assessment parameters. The satisfaction rating scales relate sidewalk condition pertaining to each parameter to expected satisfaction rating provided by pedestrians used to the old city conditions.

Six perception rating models were developed to predict ordered satisfaction ratings (in 1–5 scale) for infrastructure conditions for the six PLOS assessment parameters using Ordered Probit Models, which takes into account the variability in human perception. Randomised design of experiments for different scenarios were used to relate infrastructure conditions affecting PLOS assessment parameters and satisfaction perception ratings. The perception ratings for the six PLOS assessment parameters can be predicted using the model which requires the sidewalk condition and this can be obtained by surveying the

sidewalk condition using the survey guidelines proposed in this work. This helps to do away with the requirement of pedestrian survey for PLOS assessment. The proposed perception rating models accommodate a wide range of sidewalk infrastructure variability as expected in the conceptualized old city settings and can be used for assessing all types of walking conditions.

The proposed PLOS assessment model is an effort to eliminate variability in outcomes of various PLOS models suggested in literature and suggest a methodology for eliminating pedestrian survey for PLOS assessment with models using qualitative parameters. The perception rating models developed in the study can not only be used for determining PLOS of a sidewalk stretch but may be used as a tool for designing focused sidewalk improvement strategies as minute contribution of each underlying factor in PLOS perception may be obtained from the perception rating models as discussed in detail in the paper. Also the proposed framework for development of perception rating models may be used as a guideline for development of similar perception rating models for other types of cities and land-use conditions.

Author contributions There is no single Pedestrian Level of Service (PLOS) assessment model which systematically takes into account the contribution of all relevant factors in deciding the level of service provided by sidewalks. Also, no comprehensive PLOS assessment model is available for old cities having mixed land-use where well-defined pedestrian facilities may not always exist. Thus the authors: Developed a comprehensive PLOS assessment model for mixed land-use urban areas of old cities. The model is developed using a list of 24 relevant factors for mixed land-use areas of old cities from literature. Importance survey for the identified list of factors was conducted with 550 pedestrians from urban areas of Patna and Gaya, India. Both the cities meet the criteria of old cities, as conceptualized in this work, and have predominantly mixed land-use. Principal Component Analysis (PCA) was used to group and reduce the number of factors and find the important factor groups or parameters by identifying the underlying factor structure. Six important parameters were identified namely safety issues under pedestrian traffic interaction, condition of pedestrian infrastructure, pedestrian convenience and sense of security, night time walking, encroachment and walking comfort. The perceived level of service of sidewalk depends on the perceived satisfaction of pedestrians with respect to these parameters. The available PLOS assessment models consider perceived satisfaction of pedestrians as scaled perception ratings. The perceived satisfaction varies between individuals and thus involves subjectivity in PLOS assessment. To eliminate subjectivity in PLOS assessment, the authors. Developed satisfaction rating prediction model for all the identified parameters. The satisfaction rating for a parameter depends on the condition of the underlying factors. The condition of each of the factors were categorized into four levels from best to worst. Random experimental condition for a parameter was defined by combination of factor conditions. The randomised conditions for each parameter was designed using D-optimal design of experiments. 16 conditions were obtained for each parameter. Satisfaction rating survey was conducted with 780 participants and each participant was given 16 randomised experiments. Ordered Satisfaction rating prediction models were developed with Ordered Probit model for each parameter. These models relate condition of sidewalk facility with perceived satisfaction in the form of scaled rating.

Availability of data and material All data, models and code generated or used during the study are available from the corresponding author by request. Importance survey data, Perception survey experiment data.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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