

## Factor Structure Analysis for Pedestrian Level of Service Assessment using Structural Equation Modelling

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**Abstract-** Pedestrian facilities are aimed at providing proper walking infrastructure and environment to promote walking in cities and needs to serve the desired requirements of users. It is important to assess the level of service (LOS) provided by such facilities. Various guidelines are available for assessing LOS of sidewalks, midblock crossings and pedestrians walking along the carriageway. However, the guidelines and factors considered for assessment are diverse and no single guideline is available that comprehensively takes into account all variables relevant for both sidewalks and crossings and for mixed land use settings.

This work thus attempts to identify factors and their underlying variables and also the relative importance of the factors in determining LOS of pedestrian facilities in mixed land use areas. For this purpose, the study systematically identifies a comprehensive list of 20 important variables associated with LOS assessment for pedestrian facilities from literature. A survey was conducted of a heterogeneous group of 720 pedestrians from Patna, India to find importance perceptions of all the above identified variables. The important factors and their significant underlying variables were then identified using Exploratory Factor Analysis and the factor structure was confirmed using Structural Equation Model using survey data. Five factors namely Infrastructure, Crossing issues, Security, Sidewalk encroachments and Safety were identified with 13 significant underlying variables. It was observed that the crossing facility conditions predominantly influence the perception of LOS of pedestrian facilities. The findings of the study can be used by urban planners in focusing their improvement efforts for pedestrian facilities.

**Keywords** - Pedestrian Facilities, Level of Service, PCA, Structural Equation Model

### I. INTRODUCTION

Pedestrian infrastructure and environment are a vital part of transportation infrastructure and play an important role in attracting pedestrians, who walk for work or health benefits. Proper walking infrastructure can help reduce dependence on vehicles and thereby reduce road congestion. However, due to the current focus of urban planners (or policy makers) on vehicle-oriented transportation infrastructure development, proper pedestrian infrastructure, which provides safe, comfortable and secure walking environment, is often lacking. Pedestrian facilities need to be designed for catering to pedestrian needs [1]. Assessment of level of service (LOS) of existing pedestrian facilities should thus consider their ability to cater to pedestrian needs. Level of service perception of any pedestrian facility depends on condition of the facility. The importance of various factors that affect perceptions of level of service of pedestrian facilities vary with socio-demographic conditions of pedestrians [2-8]. Significant perception variation is observed with age [9-10] and gender [11-12]. Traffic condition [13] and walking in a group [14] also influence level of service perception of pedestrian facilities. Thus, while designing pedestrian facilities, needs of pedestrians from all socio-demographic strata should be systematically assessed and considered. To assess perceived LOS of existing pedestrian facilities, the factors influencing pedestrian perceptions need to be identified. The perceived LOS of a pedestrian facility depends on walking comfort, convenience and sense of safety and security offered by the pedestrian facility, and these factors need to be considered while designing pedestrian facilities.

A wide range of literature is available which attempt to provide guidelines for LOS assessment of pedestrian facilities [1, 15, 16-19]. Researchers have focused on providing separate LOS assessment guidelines for sidewalks [20], mid-block crossings [16] and for pedestrian movements along the carriageway where well defined pedestrian facilities are not available [20]. The LOS guidelines for sidewalks are mostly land-use specific and researchers proposed different guidelines for different land-use areas [16]. LOS guidelines for mixed land-use areas are limited [16, 20]. Also different researchers used different factors while developing LOS guidelines and there is no consensus among the guidelines on the factors used [21]. Asadi-Shekari et al., 2014 [22] proposed use of 27 attributes, both qualitative and quantitative, to assess LOS of pedestrian facilities. The attributes used included the security related factors such as presence of regular police patrolling and availability of CCTV cameras. Among qualitative factors, Sahani et al. (2017) [23] included safety related factors while proposing LOS guidelines for

pedestrian facilities. Sarkar (1993)[24] proposed a LOS assessment framework considering attributes like comfort, convenience, attractiveness, security, continuity, safety and system coherence but did not consider the effect of infrastructure variables like sidewalk width and condition while assessing LOS. Khisty (1994) [1] highlighted importance of continuity of sidewalks in LOS perception. Bivina et al. (2018) [25] proposed use of combined qualitative and quantitative attributes for LOS assessment of pedestrian facilities but did not include the aspects related to presence of amenities along the facility. For midblock crossings researchers have proposed use of traffic volume and speed for LOS assessment. With wide variation in guidelines and use of factors for assessment of pedestrian infrastructure it is difficult to have proper assessment of pedestrian infrastructure which reflects its complete usability. Thus, it is important to systematically assess the factors that pedestrians deem important for pedestrian facility and develop a guideline for the factors that needs to be considered. Also, limited guidelines for factors that need to be considered while assessing pedestrian infrastructure as a whole, including both sidewalks and crosswalks are available. Thus, this work attempts to

1. Systematically identify the important variables associated with LOS assessment for pedestrian facilities from literature.
2. Conduct survey of a heterogeneous group of pedestrians representing all socio-demographic strata to find importance perceptions of all the above variables for mixed land use areas.
3. Identify important factors and their significant underlying variables from the comprehensive list of variables identified from literature. The factors were identified using Exploratory Factor Analysis and the factor structure was confirmed using Structural Equation Model (SEM) using survey data of pedestrians' perception of importance of individual variables.

The next section gives the overall methodology of the work. Section 3 provides the details of data required and collected for this study. Section 4 analyses and discusses the results obtained. In section 5, the conclusions and findings from this work are explained.

## II. METHODOLOGY

The present work aims to study the micro level influence of different contributing variables on perceived LOS for pedestrian facilities for old cities having mixed land use. Figure 1 provides a detailed account of the present work. Initially an exhaustive list of variables influencing LOS perceptions for pedestrian facilities was identified from literature. Pedestrian survey was conducted to understand importance of these variables in 5-point Likert scale.

The importance ratings for the identified variables obtained from the survey was used to identify important factors and their underlying variables that influence the perceived LOS for pedestrian facilities by conducting exploratory factor analysis using Principal Component Analysis. The factor structure identified by exploratory factor analysis was then verified using confirmatory factor analysis using structural equation modelling (SEM).

The next sub section gives a brief theoretical overview of Factor analysis using Principal Component Analysis (PCA). Subsection 2.2 details the theoretical background for confirmatory factor analysis using structural equation modelling.

### 2.1 Exploratory Factor analysis using PCA

Exploratory factory analysis was conducted using PCA. PCA reduces dimensionality of data 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. The eigenvalue indicates the relative importance of each factor in accounting for the particular set of variables being analysed. Principal components analysis of 20 identified variables was conducted using IBM SPSS 16 to obtain the important factors for PLOS assessment.

### 2.2 Confirmatory Factor analysis using SEM

SEM is used for confirming the factor structure obtained at the exploratory phase. SEM is a multivariate technique that can simultaneously estimate dependence relationships between a number of variables. The variables are of two types namely manifest or observed variables and latent or unobserved variables [26]. SEM allows modeling of any phenomenon considering endogenous or dependent and exogenous or independent latent variables, and permits the evaluation of both the direction and strength of casual effects among these variables using the latent variable model. SEM consist of series of multiple regression equations which can be simultaneously estimated and can be expressed as given in equation 1.

$$y = i + Xb + e \quad (1)$$

Where,  $y$  = a vector containing observed scores on the dependent variable,  $i$  is a vector of y-intercepts,  $X$  is a matrix of continuously distributed independent variables,  $b$  is the vector of regression weights, and  $e$  is the vector of error. In the current study, structural equation modelling was used to conduct confirmatory factor analysis using Amos 20. The factors identified in previous section are considered as latent variables and the underlying variables identified are used as observed variables.

### III. DATA

The work uses two forms of primary survey data. First part includes the importance rating survey of 20 identified variables on five-point Likert scale. Detailed description of identified variables is given in Table 1.

Table - 1 Description of variables

Variables	Code	Description
Footpath width	FW	Sidewalks should be sufficiently wide so that pedestrians can walk easily without obstruction from another pedestrian. Minimum width of 1.5 m is required. Lesser width discourages walking
Footpath height	FH	Maximum desirable height is 15c.m. High footpath reduces accessibility especially for old person. It also provide sense of safety among pedestrian.
Condition/Quality of footpath surface (Smooth/Broken)	QFS	Condition of sidewalk determine how difficult or convenient a surface is for walking. An accessible sidewalk surface should be firm, stable, slip-resistant and free from cracks and bumps.
Frequent change of footpath height	FFH	Frequent change in height or cut for giving way decreases pedestrians' smooth mobility especially for aged persons and persons with disability.
Presence of unplanned median cut which is used for crossing	UMC	Its presence encourages pedestrian to cross even without the availability of designated crossing facilities and increases the risk for the crash.
Presence of traffic control/traffic police at crossing location	TCL	It enhances the safety for the pedestrian and encourages pedestrian to cross safely.
Presence of pedestrian foot over bridges with stairs at regular intervals	PFS	Its presence encourages pedestrian to cross even there is absence of designated cross walk facilities such as Zebra crossing, traffic control devices, traffic police etc. It is highly safe infrastructure for pedestrian crossing.
Availability of lighting facility at night	LN	Adequate lighting facility enhance the visibility. Its availability along the street gives a sense of security to pedestrian.
Regular police patrolling during night	PPN	It provide sense of security against any crime. Regular police patrolling encourages pedestrian to walk.
Pedestrian volume at night	PC	Pedestrian volume at night enhances sense of security against any crime. It encourages more people to walk.
Availability of CCTV cameras to record crime	CCTV	Along the sidewalk CCTV is installed to record the activities. It act as a passive surveillance and enhance security perception of pedestrian.
Effect of Encroachments due to temporary vendors on sidewalks	ETV	Presence of encroachment reduces the clear space of sidewalks and it lower the comfort level of pedestrians.

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Effect of Illegally parked vehicles on sidewalk	IPV	Illegally parked vehicles limit the space for walking . It discourages pedestrian to walk on the sidewalk and forces pedestrian to walk on the road.
Buffer zone between sidewalk and carriageway	BZ	Its presence reduces pedestrian-vehicle conflicts and potential collisions. This increase sense of safety among pedestrian and encourage them to walk.
Traffic speed on carriageway	TS	High traffic speed discourages pedestrian to use sidewalk. It also increases risk for pedestrian safety. Presence of separators provide sense of safety to pedestrian.
Availability of Underpass, foot overbridge etc.	UFS	It provide safety while crossing the carriageway and avoid pedestrian traffic interaction.
Availability of shades/trees for pedestrian	ST	Shades along sidewalk provide comfort while walking especially against harsh climate. This facilities can be provided by planting trees or providing weather protection.
Availability of ramps to access sidewalk by pedestrian	RAS	It provide convenient accessibility to sidewalk especially for old aged person and women. Slope of ramp should be gentle and slip-resistant.
Routine sidewalk maintenance for cleanliness	RSM	Regular cleaning of sidewalk encourages pedestrian to walk. Cleaned sidewalk provide pleasant walking condition and enhances convenience for pedestrian.
Effect of open stinking waste bin near sidewalk	OSW	Open and stinking waste bin near sidewalk makes very unpleasant walking environment. It discourages pedestrian to use such sidewalk.

Importance rating survey was conducted in five major localities of Patna, Bihar, India namely Bailey Road, Boring Road, Ashok Rajpath, Rajendra Nagar and Kankarbagh and response was collected from 720 pedestrians. Respondents were asked to rate importance for all 20 selected variables on five point Likert scale where 1 represent pleasant condition and 5 represents unsuitable conditions. Respondents are categorized based on age group, gender and profession. Among the 720 participants 16% of pedestrians were below the age of 20 years; 63% were of age group between 21 – 50 years; 21% were elderly pedestrians with age more than 50 years. Among the 720 participants, 68% of the respondent were male and rest 32% were female participants. Sample size of 720 is adequate at 99 % significance [27]. Out of these 720 responses 510 responses was used for exploratory analysis. The remaining 210 responses were used for confirmatory analysis of the factor structure obtained in the exploratory stage.

### IV. RESULTS – ANALYSIS AND DISCUSSION

Exploratory Factor Analysis (EFA) was conducted with 510 (70%) responses to obtain the important factors and their underlying contributing variables. The remaining 210 responses were used for confirming the factor structure obtained in the exploratory stage using SEM . Subsection 4.1 describes the results of EFA using PCA, 4.2 details the confirmatory analysis using SEM.

#### 4.1 Exploratory Factor Analysis

Principal Component Analysis (PCA), the most common method of exploratory factor analysis, was conducted with the 20 identified variables to obtain the important factors for level of service assessment of pedestrian facilities. Scale Reliability for scaled responses was checked using Cronbach Alpha value. The Cronbach Alpha value obtained was 0.823, indicating acceptable level of internal consistency of the scale used. Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy test value obtained was 0.839. This value is also very close to 1 which indicates that factor analysis should yield distinct and reliable variables. Bartlett's test of sphericity had a value of which was less than 0.05 significance level. This indicates that the correlation matrix is not an identity matrix, the variables are related and therefore suitable for structure detection. Table 2 details the factors identified and their underlying variables obtained from exploratory factor analysis using PCA.

Table - 2 Factors affecting LOS perception

Note: Factor loading  $\geq 0.5$  is considered.

It may be observed from Table 2 that five important distinct factors namely *Infrastructure*, *Crossing issues*, *Security*, *Encroachment issues* and *Safety* could be extracted from the 20 variables for PLOS assessment. 13 variables which are significantly loaded to the factors are shown in table. These factors are designated as latent variables and depends on certain underlying variables. The factor loadings provided in Table 2 are indicative of

Factors	Underlying Variables	Code	Factor Loading
Infrastructure (INF)	Footpath width	FW	0.785
	Footpath height	FH	0.745
	Condition/Quality of footpath surface (Smooth/ Broken)	QFS	0.692
	No of changes in footpath height per km	FFH	0.569
Crossing Issues (CRS)	Presence of unplanned median cut which is used for crossing	UMC	0.651
	Presence of traffic control/traffic police at crossing location	TCL	0.704
	Presence of pedestrian foot over bridges with stairs at regular intervals	PFS	0.551
Security (PSC)	Regular police patrolling during night	PPN	0.679
	Availability of CCTV cameras to record crime	CCTV	0.746
Sidewalk Encroachments (SEN)	Effect of Encroachments due to temporary vendors on sidewalks	ETV	0.636
	Effect of Illegally parked vehicles on sidewalk	IPV	0.729
Safety (PSF)	Buffer zone between sidewalk and carriageway	BZ	0.601
	Traffic speed on carriageway	TS	0.747

the extent of influence of underlying variables towards the identified factor. The underlying variables influencing factor *Infrastructure* includes sidewalk width, height, condition of sidewalk surface and change in height per kilometre. The underlying variables influencing factor *Crossing issues* include the presence of unplanned median, presence of traffic control at crossing location and presence of pedestrian foot over bridges with stairs at regular intervals. The underlying variables influencing factor *Security* includes availability of CCTV cameras to record crime and police patrolling during night. The underlying variables influencing factor *Encroachment issues* include temporary vendors on sidewalks and illegally parked vehicles on sidewalk. The underlying variables influencing factor *Safety* is influenced by buffer zone between sidewalk and carriageway and traffic speed on carriageway. The next section details the confirmatory analysis for confirming the factor structure.

#### 4.2 Confirmatory Factor Analysis using SEM

The factors obtained from exploratory factor analysis was validated with confirmatory factor analysis using SEM. The factors obtained in exploratory stage are the latent variables and the underlying variables influencing the factors, obtained from EFA and detailed in Table 2, are the measurable exogenous variables. The model has five latent exogenous factors namely Infrastructure, Crossing issues, Security, Sidewalk encroachments and

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Safety and 13 exogenous observed variables. SEM was used to analyze the relationship between endogenous or latent factors and exogenous or observed variables and also between latent variables. The detailed model structure is shown in Figure 1.

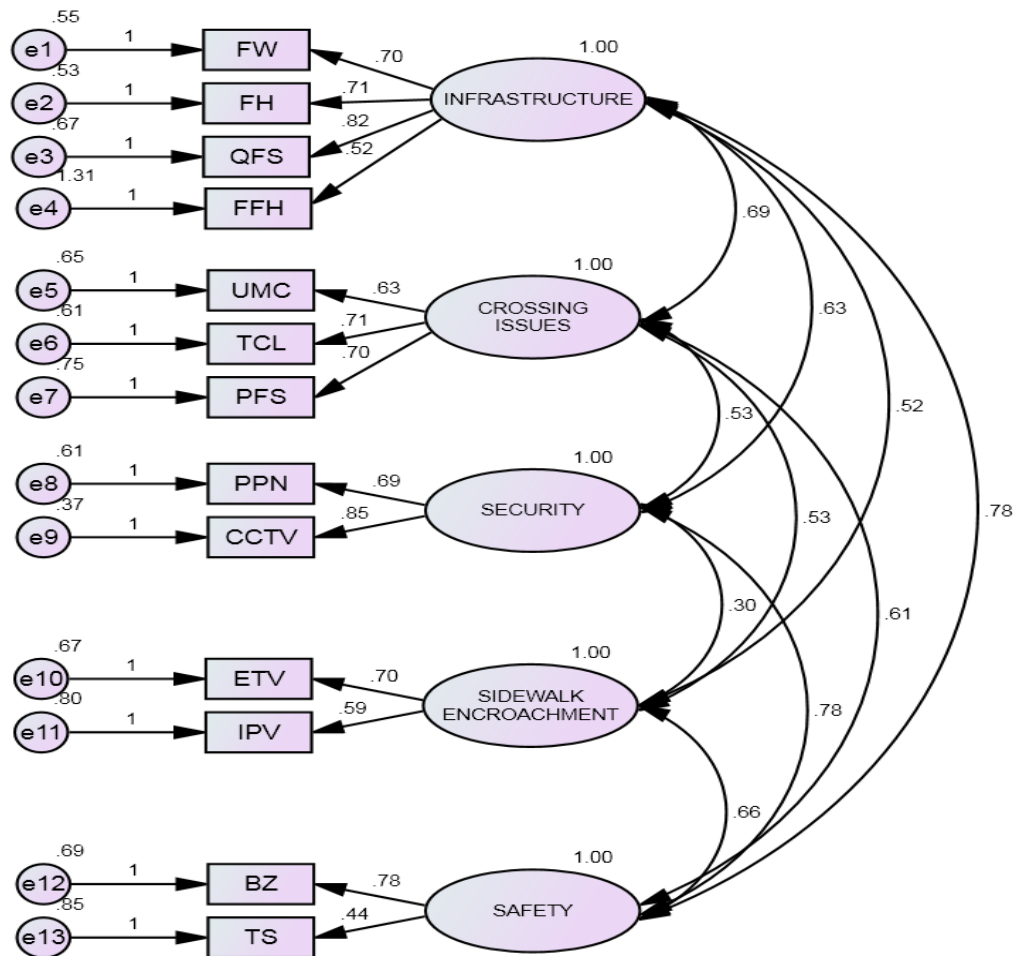


Figure 1. Structural equation model for variables and factors contribution for perceived LOS.

The goodness of fit for SEM model was assessed using Root Mean Square Error of Approximation (*RMSEA*), Comparative Fit Index (*CFI*), Normed Fit Index (*NFI*), Tucker Lewis Index (*TLI*), and *CMIN/DF*. *RMSEA* value obtained for the model was 0.063 and a value less than 0.08 is considered as good fit [28-29]. *CFI* value obtained for this model was 0.930 which indicates that the model fit is good. Also, *NFI* value of 0.861 and *TLI* value of 0.900 indicates an acceptable model fit. The *CMIN/DF* value obtained for the model was 1.826 which is within the acceptable value being less than 5.

Table - 2 Relation between exogenous latent factors and observed variables

Latent endogenous factor	Observed exogenous variable	Standardized Regression Weights	Estimates	Standard Error (SE)	Critical Ratio (CR)	P Value
Infrastructure	FW	0.685	0.700	0.069	10.124	0.000
	FH	0.701	0.715	0.068	10.434	0.000
	QFS	0.709	0.823	0.078	10.583	0.000
	FFH	0.415	0.522	0.092	5.647	0.000
Crossing Issues	UMC	0.616	0.632	0.076	8.352	0.000
	TCL	0.674	0.711	0.077	9.220	0.000
	PFS	0.629	0.701	0.082	8.544	0.000

Security	PPN	0.663	0.692	0.076	9.113	0.000
	CCTV	0.813	0.853	0.078	10.917	0.000
Encroachment	ETV	0.649	0.697	0.101	6.867	0.000
	IPV	0.410	0.555	0.095	6.275	0.000
Safety	BZ	0.704	0.683	0.101	7.710	0.000
	TS	0.499	0.433	0.079	5.580	0.000

Table 3 provides standardized regression weights (SRWs) and estimates for each predictor or observed variable for outcome or latent variables. The SRW allows evaluation of the relative contributions of each predictor variable for each outcome variable. The standard error (SE), Critical Ratio (CR) and p value may be used to check whether the variable is a significant explanatory variable for the particular latent variable. It can be observed from Table 3 that all the observed variables have significant contribution towards the latent variables. This confirms the factor structure obtained from exploratory analysis.

It may be observed that for Infrastructure, the quality of footpath surface, footpath height and width are all important and have significant contribution as observed from SRW values above 0.6. QFS and FH have greatest loadings on the Infrastructure and thus may be inferred to have maximum influence over perception of pedestrians about the infrastructure. Frequent footpath height change (FFH) has lowest SRW value of 0.415, indicating that its relative contribution in determining the perception about Infrastructure is lowest. For crossing issues, all the three underlying variables UMC, TCL and PFS have close SRW values indicating that all the underlying variables have similar contribution in determining the perception about crossing issues. Out of the two underlying variables for Security issues, availability of CCTV, with a value of 0.813, has a high impact on sense of security for pedestrians. For Pedestrian safety, the pedestrians consider buffer zone to be more important than traffic speed on carriageway (TS). Table 4 provides the estimate of errors (*e*) for the measurable variables.

Table - 3 Estimate for Errors

Error	Estimate	S.E.	C.R.	P
e1	0.553	0.069	8.002	0.000
e2	0.527	0.068	7.779	0.000
e3	0.669	0.087	7.662	0.000
e4	1.311	0.135	9.714	0.000
e5	0.654	0.082	7.977	0.000
e6	0.606	0.085	7.131	0.000
e7	0.752	0.096	7.815	0.000
e8	0.612	0.083	7.407	0.000
e9	0.374	0.094	3.986	0.000
e10	0.667	0.126	5.31	0.000
e11	0.795	0.11	7.211	0.000
e12	0.693	0.133	5.211	0.000
e13	0.848	0.091	9.338	0.000

Table 5 shows the covariances among the latent variables and their statistical significance. Whenever the p values are less than 0.01, the covariances are statistically significant. The covariance value is a measure of linear association between the two latent variables, a positive covariance indicating that the two variables are directly related and negative indicating the two variables to be inversely related.

Table - 5 Covariance between latent exogenous factors

Latent exogenous factor	Latent exogenous factor	Estimate	S.E.	C.R.	P
Infrastructure	Sidewalk Encroachment	0.516	0.096	5.36	0.000
Crossing Issues	Sidewalk Encroachment	0.531	0.102	5.21	0.000

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Infrastructure	Pedestrian Crossing Issues	0.694	0.068	10.3	0.000
Security	Sidewalk Encroachment	0.301	0.106	2.84	0.005
Crossing Issues	Pedestrian Security	0.533	0.082	6.47	0.000
Security	Pedestrian Safety	0.778	0.099	7.88	0.000
Infrastructure	Pedestrian Security	0.632	0.07	8.99	0.000
Sidewalk Encroachment	Pedestrian Safety	0.664	0.122	5.45	0.000
Infrastructure	Pedestrian Safety	0.777	0.094	8.22	0.000
Crossing Issues	Pedestrian Safety	0.614	0.105	5.86	0.000

It may be observed from Table 5 that latent variable infrastructure significantly covary with safety, security, sidewalk encroachment and crossing issues. To improve footpath infrastructure, increased width, height, QFS and reduced frequency of height change needs is important. With improvement in pedestrian crossing facilities, there will be a perception of improved infrastructure. Pedestrian safety and security will improve when infrastructure is improved. The association between infrastructure and safety, security, encroachment issues, crossing issues are positive. The positive covariance between infrastructure and safety and security indicates that improvement in infrastructure have positive effect on safety and security perception of pedestrian infrastructure. The positive covariance between encroachment issues and infrastructure indicates that with improved encroachment issues i.e. reduced encroachment the pedestrian infrastructure facility, like available width for walking, is improved. The positive covariance between encroachment and safety indicates that if sidewalks are free from encroachment, the pedestrians will not be forced to share their path with vehicle carriageway and hence will feel safer while walking. The positive covariance between crossing infrastructure and safety or safety from pedestrian traffic interaction indicates that improved crossing facilities will ensure improved safety of pedestrian infrastructure.

#### V. CONCLUSION

The study focused on systematically determining the factors and their relative contribution on LOS perception of pedestrian facilities in old cities having mixed land use. This provides a basic guideline on the factors that need to be considered for development of level of service prediction models. The study initially identifies an exhaustive list of variables that were considered for LOS assessment of pedestrian facilities by various researchers worldwide. The importance of these variables in mixed land use settings was assessed through a survey of 720 pedestrians from the city of Patna, Bihar, India. The importance was recorded in five point Likert scale for each variable. The important factors and their underlying variables were obtained systematically by exploratory factor analysis and this factor structure was verified using confirmatory factor analysis. Five factors namely Infrastructure, Crossing issues, Security, Sidewalk encroachments and Safety were identified with 13 underlying measurable variables significantly loaded to these factors. The factor structure also indicated the contribution of individual variables and their relative perceived importance. It could be observed that the inclusion of variables like frequent change in footpath height, temporary encroachment by illegally parked vehicles and speed of traffic in the carriageway was perceived to be less important than the other variables like footpath width and height, encroachment due to shops and vendors and presence of adequate buffer. The variables Availability of CCTV cameras to record crime has highest relative perceived importance where as Traffic speed on carriageway has the lowest relative perceived importance.

This study provides the factors and their relative importance in determining LOS of pedestrian facilities in mixed land use settings. The findings of the study can be used by urban planners in focusing their improvement efforts for pedestrian facilities.

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