Identification of Measures of Effectiveness (MOEs) for developing Pedestrian Level of Service (PLOS): A Theoretical Approach using Expert Opinion on a Fuzzy Likert (FL) Scale

doi: 10.14246/irspsd.7.4_56

International review for spatial planning and sustainable development, Vol.7 No.4 (2019), 56-82
ISSN: 2187-3666 (online)
DOI: http://dx.doi.org/10.14246/irspsd.7.4_56

Identification of Measures of Effectiveness (MOEs) for developing Pedestrian Level of Service (PLOS)

A Theoretical Approach using Expert Opinion on a Fuzzy Likert (FL) Scale

Dipanjan Nag[1*] and Arkopal Kishore Goswami[1]
[1]*Ranbir & Chitra Gupta School of Infrastructure Design and Management, Indian Institute of Technology Kharagpur*
** Corresponding Author, Email: el.diablo.diablo78@gmail.com*

Received: February 15, 2018; Accepted: December 10th, 2018

Key words: PLOS, MOEs, Fuzzy-Likert, TOPSIS, RIDIT, GRA, Ranking Techniques

Abstract: A wide range of literature is available about assessing Pedestrian Level of Service (PLOS), which use different approaches and different Measures of Effectiveness (MOEs) — or attributes — to characterise the PLOS models. In recent years, there has been a growing consensus of capturing three different constructs in the PLOS model — flow characteristics of the pedestrian traffic, the built walking environment and the user's perception. Existing PLOS literature has been capturing these broad constructs, but not in a combined fashion. This paper explores the MOEs responsible for developing such a PLOS and records expert opinion surveys on a Fuzzy-Likert (FL) scale. Three established rating data techniques —TOPSIS, RIDIT are GRA are then utilised to get a ranking of the MOEs that could be further used to develop the said PLOS model. It is seen from these rankings that of the top 10 MOEs preferred by the experts, nine belong to the broad construct categories of design (built walking environment) and the user's perception, and only one belongs to the broad construct of flow characteristics. This result reinforces the fact that the PLOS has to be created using all the three broad constructs and not separately — or in pairs — as had been done so far. This study also deals with the effectiveness of using an FL scale compared to a Likert scale as a response measurement tool and found that an FL scale is 13.08% more accurate than a Likert scale in measuring ordinal responses.

1. INTRODUCTION

Cities around the world are becoming increasingly sensitive to the concept of sustainable development. The concept goes beyond the boundaries of traditional knowledge systems of science and business development to accommodate human development and values (Boquet, 2014).

A way of attaining sustainability and assuring the well-being of residents is through introducing a smart transport system — one that is reliable, safe, eco-friendly and affordable. Walking as a mode of transport provides direct access to many destinations and is, sometimes, the last-mile connectivity for users of other modes of public transit. In addition, people walk for recreation and exercise.

There has been a growing consensus among researchers to enhance the importance of this mode because of the numerous benefits it provides. This has created the need to measure the performance of pedestrian facilities to assess the operational quality, existing gaps in service, requirements for upgrades, etc. (Sisiopiku, Byrd, & Chittoor, 2007). The Pedestrian Level of Service (PLOS) is a measure to understand the Level of Service (LOS) of a pedestrian facility, or system. The LOS is the overall measure of all service characteristics that affect users of a system (Khisty, 1994).

The existing literature on PLOS proposes various ways of assessing the quality of operations of a pedestrian facility. Some of the methods evaluate PLOS using pedestrian flow characteristics (like speed, density, flow, etc.) while other researchers have defined PLOS based on the walking environment aspect (like the width of the facility, comfort, convenience, etc.).

This paper aims to identify the essential factors that could be used for developing a PLOS of sidewalks.

To achieve this, an in-depth literature review (Section 2) of the existing PLOS measures has been done to understand the Measures of Effectiveness (MOE) involved in each method, but some of the MOEs might be defining the same construct or measuring the same factor. Thus, to understand the differences, a Fuzzy-Likert (FL) scale-based expert opinion survey was done to identify the significant factors involved in the assessment process.

Thereafter, three established rating data techniques—TOPSIS, RIDIT and GRA were used to analyse the Fuzzy-Likert responses from the experts to understand the importance of MOEs in the context of PLOS assessment. The use of three techniques was done to identify variation, if any, in the derived ranking of the MOEs. A brief background of these methods and how they are carried out with respect to the present study will be presented in Section 3 followed by dataset analysis in Section 4.

2. LITERATURE REVIEW

PLOS is the Level of Service as defined for pedestrian facilities. As per Transportation Research Board (2000), LOS is “a qualitative measure describing operational conditions within a traffic stream, based on service measures such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort and convenience.” The major task in assessment of LOS is to understand the underlying constructs, which is quantified by the key parameters — also called the measures of effectiveness (MOE) (Kadali & Vedagiri, 2016).

Fruin (1971), Pushkarev and Zupan (1975) and Polus, Schofer, and Ushpiz (1983) undertook the earliest work on PLOS. These works defined PLOS as a function of MOEs such as walking speed, density/area module and flow of pedestrians, which define the construct of flow characteristics. Tanaboriboon and Guyano (1989) carried out LOS classifications of pedestrians in Bangkok using the flow characteristics as the MOE and compared it with the results of Fruin, Polus, and others. He concluded that the flow characteristics of “pedestrian area occupancies determined in this study are lower than those obtained in the United States, but the flows that can be accommodated in each LOS are higher”, which indicates a cultural bias among the pedestrians of different cultures. Different researchers like Kotkar, Rastogi, and Chandra (2010) and Rastogi, Ilango, and Chandra (2013) have established this for the Indian condition. Fruin’s (1971) method was later formalised by the Transportation Research Board (2000), which uses the calculation of pedestrians per minute per foot (ped./min/ft.) as the basis for LOS classification. The only problem (as noted by Landis et al. (2001)) faced by this method is that it can only assess existing sidewalks and that too only in the perspective of effective width of sidewalk. Consequently it cannot be used to evaluate or prioritise roadways for sidewalk retrofit construction.

Flow characteristics are crucial in identifying the capacity of a facility, but not the sufficient condition in the assessment of PLOS. Various researchers like Khisty (1994), Landis et al. (2001) and Sisiopiku, Byrd, and Chittoor (2007) have stressed upon the fact that quantifiable MOEs are not the only factors that should be taken into account while estimating the PLOS, qualitative MOEs, such as safety, security, comfort, etc., of the user are also to be factored in.

Since the LOS concept is based on measuring the quality as provided to the user, only quantitative MOEs do not describe that completely. These kinds of index (the relationship between flow, speed, and density) alone are insufficient to characterize pedestrian LOS when the pedestrian traffic is moderate or low (Kadali & Vedagiri, 2016). Critics suggest that current pedestrian LOS determination methods are modelled too closely after vehicular LOS determination methods, often resulting in inadequate and contradictory assessments or even showing good LOS values in an inhospitable walking environment (Sisiopiku, Byrd, & Chittoor, 2007). Thus, the PLOS as defined by Sarkar (1993), Khisty (1994) and Dixon (1996) uses a qualitative approach using MOEs like safety, security, continuity, comfort, system coherence, maintenance and amenities.

Contemporary researchers have shown different methods owing to the fact that, "the assessment method of PLOS should not be driven by data that can be easily measured and manipulated quantitatively but should capture the walking experience of pedestrians and planners" (Singh & Jain, 2011). A model by Landis et al. (2001) was developed through a multi-variable regression analysis based on observations from 42 directional segments under the Florida Department of Transportation (FDOT). The factors considered were mainly focused on the sidewalks, excluding the intersection conditions, and were more inclined towards the user's perception. Landis and others advocated the need for "a transferable model to objectively reflect the perceived safety or comfort of pedestrians along a roadway segment using measurable traffic and roadway variables".

Jensen (2007) used a cumulative logistic regression model to develop a PLOS as well as a Bicycle LOS for roadway segments. The model included variables that significantly influenced the level of satisfaction of users like motorised traffic volume and speed; urban land uses; rural landscapes; the types and widths of pedestrian and bicycle facilities; the numbers and widths of the drive lanes; the volumes of pedestrians, bicyclists, and parked cars; and the presence of medians, trees, and bus stops.

Muraleetharan et al. (2003) used Conjoint Technique to combine the factors affecting pedestrian LOS, he determined pedestrian LOS for sidewalks and crosswalks by combining multiple attributes affecting pedestrian travel.

Sahani, Ojha, and Bhuyan (2017) aimed at developing a model to evaluate service measure in the roadside walking environment using qualitative and quantitative analysis for pedestrians in developing countries. They used a Genetic Programming Clustering technique to find the six PLOS ranges (A-F) for sidewalks. Sahani, Praveena, and Bhuyan (2016) also showed the use of a multinomial logit model to evaluate the Service Levels of Pedestrian Facilities.

All these studies are exhaustive in their own rights, and have used different variables to describe partially the constructs of capacity-based measurement, user's perception and the quality of the built walking environment, but the intricacies of pedestrian movement and their perception of the walking environment are too complex to be limited by a standard number of variables. The combined qualitative (comfort, safety, etc.) and quantitative approach (pedestrian speed, flow, and density) is more realistic as compared with only the qualitative or quantitative approach (Kadali & Vedagiri, 2016). Hence, a systematic review of these variables from the existing literature needs to be done to check the variables that contribute significantly in elucidating the complex concept. A comprehensive list of literature reviewed is given in Table 1.

Table 1. List of Literature Reviewed
M1: Volume of Ped.; M2: Speed of Ped.; M3: Area Module (density); M4: Flowrate; M5: Speed of Vehicles; M6: Volume of Vehicles; M7: Convenience and System Coherence; M8: Presence of Sidewalk; M9: Width of Sidewalk; M10: Effective Width of Sidewalk; M11: Safety; M12: Security; M13: Surface quality; M14: Buffer between Ped. and Vehicles;

Researchers	Description	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13	M 14
Fruin (1971); (Pushkarev & Zupan, 1975); Polus, Schofer, and Ushpiz (1983)	Quantitative analysis of flow characteristics; definition of pedestrian capacity of a facility	✓	✓	✓											
Davis and Braaksma (1987)	Studied the platooning of pedestrian and adjusted PLOS criteria based on it		✓	✓	✓										
Tanaboriboon and Guyano (1989)	Quantitative analysis of flow characteristics in Bangkok			✓	✓										
Transportation Research Board	Formalised version of Fruin (1971)			✓	✓										
Transportation Research Board (2010)	Combined method of evaluating PLOS based on walking environment characteristics and available sidewalk					✓	✓			✓	✓				✓

Table 1. List of Literature Reviewed (continued)
M15: Driveway Access; M16: Perceived Ped. Volume; M17: Enclosure and Definition; Building Articulation; The Complexity of Spaces; Overhangs, Awnings, and Varied Rooflines; M18: Distance; M19: Connectivity; M20: Attractiveness/Aesthetics; M21: Continuity, Amenities; M22: Provision of Landing Area, Kerbs, Property Entrance, etc.; M23: Bicycle Volume; M24: Obstruction; M25: Parking on Sidewalk; M26: Land-use; M27: Presence of Trees; M28: Comfort; M29: Maintenance

Researchers	Description	M1	M6	M7	M9	M11	M12	M13	M14	M15	M16	M19	M20	M22	M23	M27
(Sarkar, 1993);Khisty (1994); Lopez (2006)	Physical descriptions of the walking environment; qualitative measures were analysed using weighted factors			✓		✓	✓						✓			✓
Dixon (1996)	Point system-based PLOS		✓		✓											
Gallin (2001)	Point system-based PLOS, considers a range of factors: design factors, location factors, user factors	✓			✓		✓	✓				✓		✓		
Dandan et al. (2007)	Analyses the relationship between the pedestrian’s subjective perceptions and the quality of the road physical facilities as well as the traffic flow operation	✓	✓						✓	✓					✓	
Miller, Bigelow, and Garber (2000)	Perceived LOS from people based on visual simulation										✓					

Table 1. List of Literature Reviewed (continued)

Researchers	Description	M 1	M 2	M 3	M 4	M 5	M 6	M 8	M 9	M 10	M 11	M 14	M 17	M 18	M 19	M 20	M 21	M 26	M 27
Jaskiewicz (2000)	Pedestrian environment evaluation criteria based on the principles of urban design							✓	✓	✓		✓	✓		✓	✓			✓
Bandara et al. (1994)	Network measure from grade separated pedestrian systems													✓	✓			✓	
City of Fort Collins (2002)	PLOS evaluation for the city of Fort Collins									✓	✓			✓			✓		
Kim et al. (2014)	Theoretical model and PLOS based on evasive movements of the pedestrian and the pedestrian space	✓	✓	✓	✓		✓			✓									
Landis et al. (2001); (Petritsch et al., 2005)	PLOS based upon pedestrian perceptions only					✓		✓	✓			✓					✓		

Table 1. List of Literature Reviewed (continued)

Researchers	Description	M1	M2	M4	M5	M6	M8	M9	M11	M14	M19	M22	M23	M24	M26	M27	M 28	M 29
Muraleetharan et al. (2003)	Pedestrian environment evaluation criteria based on the principles of urban design			✓						✓			✓	✓				
Jensen (2007)	Network measure from grade separated pedestrian systems	✓			✓	✓		✓							✓	✓		
(Transportation Research Board, 2008)	PLOS evaluation for the city of Fort Collins	✓	✓	✓			✓	✓		✓		✓						
(Sahani, Praveena, & Bhuyan, 2016); Sahani, Ojha, and Bhuyan (2017)	The use of soft computing techniques to estimate PLOS	✓			✓	✓		✓	✓		✓			✓			✓	✓

3. METHODOLOGICAL APPROACH

3.1 Selected MOEs

A flowchart shown in Figure 1 will help explain the steps taken in the study. The first step is to select the MOEs; Table 2 shows a list of the 31 MOEs identified from the literature review followed by a broad categorisation of the constructs they measure and a brief description of the MOEs. They were selected because of their repetitive occurrences across literature.

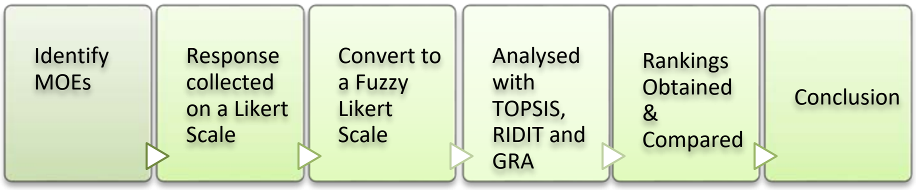


Figure 1. Methodology of the study

Table 2. MOEs selected for the study
FC: Flow Characteristics (Capacity); D: Design (Built Environment); UP: User's Perception

SL No.	MOE and code	What does it measure?	Broad Construct FC	D	UP
1.	Walking Speed (WS)	The speed at which the pedestrian walks.	✓		
2.	Area Module (AM)	The area occupied per pedestrian; inverse of density.	✓		
3.	Density (Den)	Number of pedestrians per unit area.	✓		
4.	Volume of Pedestrians (FR)	Number of pedestrians per unit time per unit space (=Den*WS).	✓		
5.	Presence of Sidewalk (P_SW)	It is very normal for a major road to not have a sidewalk and for people to walk on the road edges.			✓
6.	Width of Sidewalk (W_SW)	How wide is the sidewalk?		✓	
7.	Effective Width of Sidewalk (EW_SW)	Width after subtracting the width encroached due to obstructions.		✓	
8.	Lateral Separation (Buf)	Width of the separation between the vehicular traffic stream and the pedestrian traffic stream.			✓
9.	Presence of Barrier (P_Bar)	Whether a barrier is present between the pedestrians and the vehicular traffic or not.			✓
10.	Volume of Vehicular Traffic (Vol_veh)	Number of vehicles passing through adjacent to the sidewalk facility or where the pedestrians walk.			✓
11.	Speed of Vehicular Traffic (Speed_Veh)	Speed of the vehicles going past the pedestrians.			✓
12.	Safety (Saf)	Feeling of safety from injuries due to accidents.			✓

SL No.	MOE and code	What does it measure?	Broad Construct		
			FC	D	UP
13.	Security (Sec)	How secure is the facility/road from crimes?			✓
14.	Aesthetics (Aest)	How visually appealing is the facility/road?			✓
15.	Comfort (Com)	How comfortable is it to use the facility to cover a certain distance?			✓
16.	Convenience (Con)	How convenient is it to use a facility?			✓
17.	Distance (Dist)	Distance between the origin and destination of the walking trip.			✓
18.	Connectivity (Conn)	How connected are the facilities in terms of connections to various destinations?		✓	
19.	System Coherence (Sys_coh)	Whether the facility is logical and consistent in presenting the visual statement of the area.			✓
20.	Presence of Directional Signs (P_signs)	If directional signs are present to direct pedestrians of the routes.		✓	
21.	Presence of Street Illumination (P_light)	How illuminated are the streets/facility after dark?		✓	
22.	Presence of Trees (P_tree)	Amount of trees present to enhance the visual appeal of the facility and also to provide shade.		✓	
23.	Presence of Shading Device (P_shade)	Whether facilities/roads are equipped with weather proofing elements or not.		✓	
24.	Parked Vehicle on Sidewalk (P_park veh)	Encroachment due to parked vehicles on the existing sidewalk.			✓
25.	Presence of Hawkers (P_hawker)	Encroachment due to vendors on the existing sidewalk.			✓
26.	Obstructions (Obs)	Obstruction on the existing sidewalk, like lamp posts, etc.			✓
27.	Surface Quality (S_Qual)	Quality of the surface on which the pedestrians walk.			✓
28.	Land-use (LU)	Type of land-use		✓	
29.	Accessibility (Acc)	How accessible is the sidewalk facility?		✓	
30.	Continuity (Cont)	Whether the facility is continuous or discontinuous on a particular route.		✓	
31.	Curbs, Landing/ Waiting Area, Ramps (P_Curb LA)	Presence of curb waiting areas, property entrances, etc. on a sidewalk stretch		✓	

3.2 Design of Survey Instruments and Data Collection

An online survey of expert opinion was carried out in the academic fraternity, comprising both students and teachers from reputed institutions. The questionnaire (an excerpt shown in Figure 2) consisted of questions regarding all the 31 MOEs as shown in Table 2 along with a short description of the MOE. The question consisted of two parts — firstly, to rate on a Likert scale (Likert, 1932) of 1 (least important) to 5 (highly important); and secondly, on a scale of 1 to 100, how sure they were of their rating.

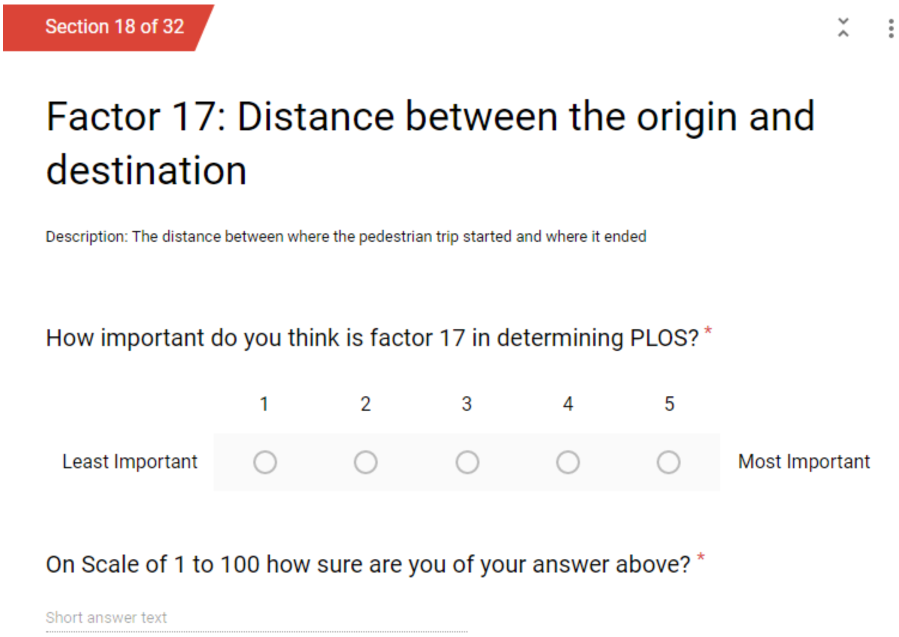


Figure 2. Excerpt of the online questionnaire

The online questionnaire was sent to 69 people, of which 30 replied with complete answers, clocking a response rate of 43.47%. It is to be noted that experts from a wide range of domains, such as urban planning, regional sciences and urban design, were surveyed.

The distribution pattern of experts is as follows: 27.77% from the transportation domain; 22.22% from the infrastructure design; 19.44% from urban planning practices; 8.33% each from the regional sciences, urban design and urban sciences domains; finally, 5.58% from the civil engineering domain. The responses were coded and converted into a digital database, and then taken forward to the next step where the Likert scale rating was transformed to the FL scale.

3.3 Fuzzy Likert Scale

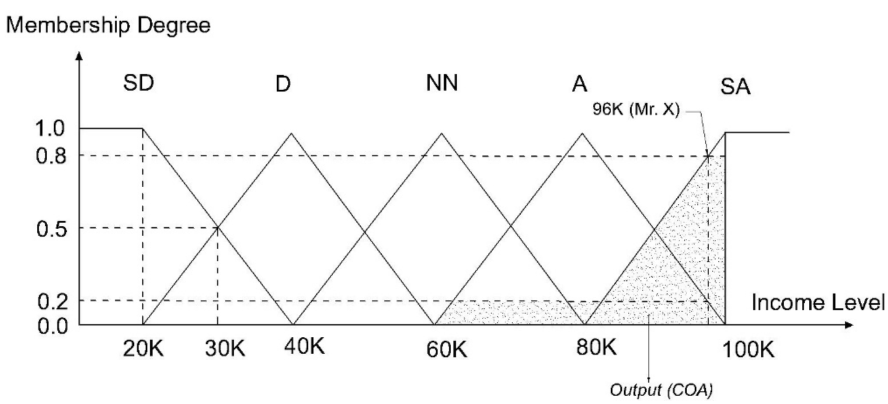


Figure 3. Membership Function used by Li (2013)

The main intention of the second part of the question (i.e. the certainty of the rating) in the online questionnaire (Section 3.2) was to construct a Fuzzy-Likert scale from a Likert scale, which can be used for improved measurement of accuracy (Li, 2013). Gil and González-Rodríguez (2012) have suggested to identify each Likert response category with a fuzzy subset from a class of operational and flexible fuzzy sets, which have been stated by 'experts' — either individual or by consensus. Further, Li (2013) has also referred to the use of consensus score — based on which it was shown that FL scale has a superior ability to capture consensus of a group than a simple Likert scale. This property of an FL scale is most important for this research, as the study involves selection of MOEs based on expert opinion—which would be a simplified task if the consensus of the group were better captured through the data.

A modified approach to the Fuzzy-Likert methodology as proposed by Li (2013) was used which, unlike the traditional Likert scale, is a continuous scale. He used the FL scale in social research for understanding perceptions of different people in judging their income level to be high. The methodology proposed by him consisted of two specific steps — fuzzification of the collected responses and defuzzification of the fuzzified information so that it can be used for the purpose of the study. In both the fuzzification and the defuzzification processes, an evenly spaced triangular function was used (see Figures 3 and 4). The triangular function is a very common function in fuzzy set theory and allows simple computation to transform input variables into fuzzy variables (Li, 2013).

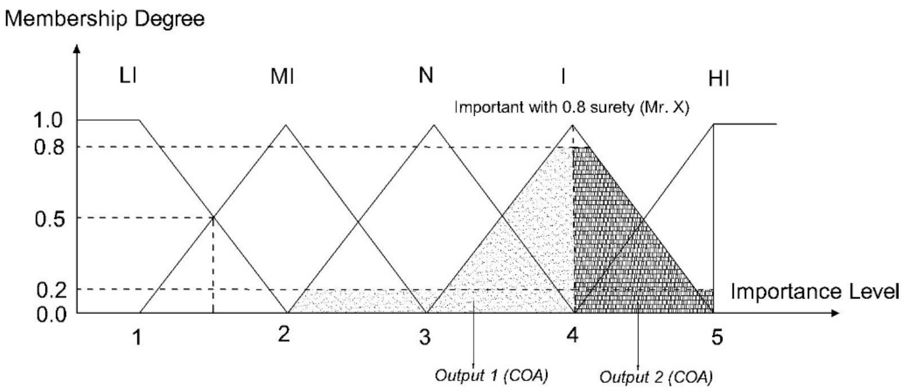


Figure 4. Membership Function used in this research

The modification in this study from Li (2013) lies in a slight variation of the membership function and the method of defuzzification. Li (2013) used a triangular function to fuzzify the question "Your income level is high" on a five-point scale from "strongly disagree" to "strongly agree", with the income on the X-axis of the membership function. This study fuzzifies the question "How important do you think *MOE_name* is in the assessment of PLOS?" on a five-point scale from "least important" to "most important", thus the issue of what quantity to put on the X-axis surfaces. This problem was resolved using a similar membership function defined by Gil and González-Rodríguez (2012), where they carried out an opinion survey of students on a particular subject. They had used the 1 to 5 rating on the X-axis, as was done for this study (see Figure 3). In the fuzzification process, Li (2013) had already characterised the membership function with the curve shown in Figure 3.When a random person, Mr X, says he "Strongly Agrees" with the fact that his—(a)"income level is high", (b) he is 80% sure about his answers, and, (c) that he has an income of 96K, then it can be ascertained the FL value will be a value in between 4 and 5. However, for the modified method used in this research, the equivalent FL score will be ambiguous (as explained in subsequent paragraphs).

The defuzzification method being the Centre of Area (COA) method (Ross, 1995) where the weighted average of the different shaded area (Figures 3 and 4) is considered using equation number 1.

$$Output = \frac{u_{lc1}.A_{lc1} + u_{lc2}.A_{lc2}}{A_{lc1} + A_{lc2}} \qquad (1)$$

Where u_{lc1}, u_{lc2} = the corresponding Likert scale values between which the FL value is assumed to lie; A_{lc1}, A_{lc2} = Area of the shaded region under the triangular function (as shown in Figure 2).

The defuzzification process has deviated from Li's (2013) methodology due to this modification of the membership function. Li (2013) had studied the social rule to understand what value of income level would be judged high or low by the society in general. Hence, the cut-off value of the income level for which a person would strongly disagree or strongly agree on the income to be "high" was established. On this ground, his methodology, uses three inputs from the respondents: (a) the Likert scale value of "strongly disagree" to "strongly agree", (b) how "sure" were they of their answer, and (c) their income level. This study, however, uses two inputs to the analysis, (a) the Likert Scale and (b) the "surety" of their response, thus it was not possible to understand which category the response might be fuzzified into. Considering Figure 4, if Mr. X thinks (a) *MOE_name* is important (Likert score: 4) in the assessment of PLOS and, (b) is 80% sure. then it cannot be confirmed if the FL score value lies between 3 and 4 or 4 and 5.

Thus, for each response collected there are two groups wherein the response might fall under, the response before it or after it. For responses with Likert scale 1 or 5 the response may fall under only one such group, i.e. the FL scale value will lie between 1 and 2 or 4 and 5, respectively, for Likert Scale values 1 and 5. Thereafter, selection of one of the groups from the two outputs, *Output 1* and *Output 2* (refer Figure 4), was dictated by the consensus score (Tastle & Wierman, 2007).

$$\text{Cns}(X) = 1 + \sum_{i=1}^{n} p_i \log_2 \left(1 - \frac{|x_i - \mu_i|}{d_x}\right) \qquad (2)$$

Where, X is the response, n is the number of the categories in a scale, x_i is the degree of agreement in category i, p_i is the probability of the occurrence of x_i; $d_x = X_{max} - X_{min}$ and is the width of categories on the measurement scale, and μ_i is the mean of the overall agreement. Applying these definitions to the traditional 5-point scale for an example, it can be found that n = 5, i ranges from 1 to 5, and $d_x = 5 - 1 = 4$.

The group of the FL category with the $\text{Cns}(X)$ closest to the Likert $\text{Cns}(X)$ of the respondents is selected as the defuzzified value. These are the final values selected for further analysis; *Final Output* of the FL scale is equal to *Output 1* or *Output 2* depending on their $\text{Cns}(X)$ score.

3.4 Ranking Techniques

The FL scores thus evaluated from the responses are then analysed to estimate the rank of the MOEs, as per the experts' opinions. The methods used were TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), RIDIT (Relative to an Identified Distribution Integral

Transformation) and GRA (Grey Relational Analysis). These three techniques are established methods as per the existing literature and had been used by Sadhukhan, Banerjee, and Maitra (2015) to establish the use of these techniques to rank the perception of light rail sub-way commuters towards seven transfer facility. The following Section will explain the techniques to some extent and their applicability in this research.

3.4.1 TOPSIS

TOPSIS is a suitable multi-criteria decision-making technique used by Hwang and Yoon (1981). Using this technique, the alternatives are ranked based on their attributes and their relative closeness (C*) to an ideal solution. Before this, the set of positive ideal solutions and negative ideal solutions are identified and the Euclidean distance of each alternative from the positive ideal solution (d^+) and the negative ideal solutions (d^-) are estimated. C* is given by equation number 3.

$$C^* = \frac{d^-}{d^+ + d^-} \qquad (3)$$

In this study, the alternatives were taken to be the MOEs identified from the literature review, as was done by Sadhukhan, Banerjee, and Maitra (2015) and all the FL scores of the experts were taken to be attribute values for the evaluation of the alternatives. Hwang and Yoon (1981) and Sadhukhan, Banerjee, and Maitra (2015) provide a more detailed explanation of the methods.

3.4.2 RIDIT

RIDIT scoring is a statistical method used to analyse ordered qualitative measurements. It was first proposed by Bross (1958), who coined the term "RIDIT" by analogy with other statistical transformations such as probit and logit. The essential condition of applying a RIDIT scoring is to have at least two groups, and one such group will be selected as the reference scale. The reference data set can be the total responses of the survey, if the population cannot be easily identified. A stepwise method for calculating RIDIT scores is given by Wu (2007). The RIDIT scoring is calculated using the following equations numbered from 4 to 9.

$$F_1 = 0.5 f_1 \qquad (4)$$

$$F_j = 0.5 f_i + \sum_{k=1}^{j} f_k \ where\ j = 2, \dots \dots . n \qquad (5)$$

Where, F_j= midpoint accumulated frequency for each category of responses and f_i =frequency for each category of responses, where i =1, 2…...n. The RIDIT value for the reference scale is,

$$R_j = \frac{F_j}{N} \ where\ j = 1, \dots \dots . . n \qquad (6)$$

Where, N = total number of responses from the survey, by definition the expected value of R for the reference data set is always 0.5 (Wu, 2007). The RIDIT value for each category in the scale is given by,

$$r_{ij} = \frac{R_j . \pi_{ij}}{\pi_i} \ where\ i = 1, \dots \dots , m \qquad (7)$$

$$\pi_i = \sum_{k=1}^{n} \pi_{ik} \qquad (8)$$

Where, m = number of categories in the scale used for survey, π_{ij} = frequency of category j for the ith scale item and π_i = short form for the summation of frequencies for scale item i across all categories. The mean RIDIT for each category is finally given by equation 9.

$$\rho_i = \sum_{k=1}^{n} r_{ik} \qquad (9)$$

A low value of ρ_i is preferred over a high value of ρ_i because a low value of ρ_i indicates a low probability of being in a negative propensity (Wu, 2007). The MOE's alternatives are ranked on this basis.

In this study, since the FL scale is not a discrete scale like the Likert scale, different categories of the scale are made discrete using smaller intervals (1, 1.25, 1.5, 1.75, 2, 2.25…………5) and the FL scores are adjusted accordingly. So, for a Likert scale *j*=5 and for the proposed FL scale *j*=17, and since there are 31 MOEs *m*=31.

Since ρ_i is a probabilistic value, the confidence interval and hypothesis testing were evaluated to assess the efficiency of the RIDIT score. When the size of the reference data set is very large relative to that of any comparison data set, equation number 10 gives the 95% confidence interval of any ρ_i.

$$CI = \rho \pm \frac{1}{\sqrt{3\pi_i}} \qquad (10)$$

The hypothesis tested whether the ρ_i value is not much deviated from the expected value of 0.5.

$$H_o: \rho_i = 0.5 \quad and\ H_1: \rho_i \neq 0.5$$

Test statistics called the Kruskal-Wallis W, given by equation number 11 follows a χ^2 distribution with (*m*-1) degrees of freedom.

$$W = 12 \sum_{i=1}^{m} \pi_i (\rho_i - 0.5)^2 \qquad (11)$$

3.4.3 GRA

Grey Relational Analysis (GRA) is a technique based upon Gray System Theory proposed by Deng (1989). Grey System Theory provides a method for abstract modelling of systems for which the information is limited, incomplete and characterized by random uncertainty. In system control theory, a system with complete information is known as a white system and a system for which the relevant information is completely unfamiliar is known as a black system; any system between these limits is known as a grey system. Wu (2007) and Sadhukhan, Banerjee, and Maitra (2015) have described the GRA steps in detail.

Like RIDIT, in GRA too, a reference scale is recognized; generally, reference data series consist of values representing the most favoured responses for the attributes of the alternatives. For the purpose of our study, the most favoured response is the best response an MOE can receive — that is 5 on an FL scale. Then, a difference matrix between the attribute scores of the reference data set and the comparison data set is calculated, and the global maximum and the minimum from the matrix are identified.

The next step is to transform each data point in each difference data series to a gray relation coefficient using equation number 12.

$$\theta_i(j) = \frac{d_{min} + \omega d_{max}}{d_i\,(j) + \omega d_{max}} \qquad (12)$$

Where, $d_i(j)$ is the j value in the d_i difference data series and ω is a coefficient having a value between 0 and 1, while 0.5 is a default value set to the model, d_{min} and d_{max} are the global minimum and maximum values from the difference matrix $d_i(j)$.

Finally, to compute the gray relation for each difference data series, equation 13 is used; the gamma function is the gray relational grade for each MOE (alternative). The alternatives are ranked based on this value, and in the study the rankings are done on the descending order of the values.

$$\Gamma_i = \frac{1}{m}\sum_{n=1}^{m} \theta_i(n) \qquad (13)$$

Where, *m* = number of respondents.

4. RESULTS AND DISCUSSION

4.1. TOPSIS Analysis

Using TOPSIS, the rankings were obtained as per Table 3. It was interesting to note that people ranked more towards the design elements such as the presence of sidewalks, width of sidewalks and such like, rather than flow characteristics such as speed and volume of pedestrians.

Table 3. TOPSIS Analysis and Ranking

MOE Code	Distance from +ve Ideal Solution	Distance from -ve Ideal Solution	Relative Closeness	Ranking	Broad Construct
WS	0.49756	0.531447	0.516466	24	Flow Characteristics (Capacity)
AM	0.477672	0.528458	0.525238	22	
Den	0.365441	0.604964	0.623414	10	
FR	0.428591	0.544004	0.559333	16	
LU	0.543581	0.500147	0.479193	26	Design (Built Environment)
Acc.	0.287244	0.651538	0.694025	6	
Cont.	0.450474	0.564855	0.556327	18	
P_Curb LA	0.341978	0.682814	0.666295	8	
W_SW	0.31094	0.621022	0.66636	7	
EW_SW	0.296335	0.706989	0.704647	5	
Conn.	0.337239	0.615172	0.64591	9	
P_signs	0.392548	0.585267	0.598546	12	
P_light	0.212156	0.707747	0.769371	2	
P_trees	0.466422	0.545916	0.539262	21	
P_shade	0.400931	0.563983	0.58449	14	
S_Qual.	0.425448	0.556722	0.566829	15	User's Perception
P_hawker	0.479696	0.527104	0.523544	23	
Obs.	0.372332	0.608962	0.620571	11	
P_SW	0.150543	0.783729	0.838866	1	
Buf	0.530663	0.467489	0.468355	27	

MOE Code	Distance from +ve Ideal Solution	Distance from -ve Ideal Solution	Relative Closeness	Ranking	Broad Construct
P_Bar	0.406357	0.515332	0.559117	17	
Vol_Veh.	0.583736	0.363984	0.384063	31	
Speed_Veh	0.498658	0.491499	0.496385	25	
Saf.	0.234293	0.729002	0.75678	3	
Sec.	0.234293	0.729002	0.75678	4	
Aest.	0.581988	0.419277	0.418747	29	
Com.	0.428181	0.521504	0.549134	19	
Con.	0.456053	0.554158	0.548557	20	
Dist.	0.63351	0.428209	0.403316	30	
Sys_coh.	0.535136	0.431273	0.446263	28	
P_park veh.	0.404284	0.592905	0.594576	13	

Let an example from Table 3 be considered, say, speed of vehicle, which is ranked at 25 due to its relative closeness (0.496385) being further away from the ideal solutions in comparison to, say, width of a sidewalk (W_SW), which is ranked at 7. W_SW is ranked higher than speed of vehicle (Speed_Veh) as it is closer to the ideal solutions (0.66636). Relative closeness is an index with value ranging from 0 to 1; as this index tends toward 1, closer is the alternative to the ideal solution.

4.2. RIDIT Analysis

The RIDIT analysis was carried out in two parts — firstly, the RIDIT values for the reference data set were calculated and then the RIDIT for the comparison data was evaluated (Table 4). The Kruskal-Wallis Statistic was used to judge the significance of the analysis (Sadhukhan, Banerjee, & Maitra, 2015).

A significantly greater Kruskal-Wallis (W) value of 143.56 as compared to the critical chi-squared value with degrees of freedom of 30 [χ^2_{31-1} =43.77] at the 0.05 significance level indicates that the responses toward the importance of the 31 MOEs among respondents are statistically significantly different. In addition, the Lower Bound (LB) and Upper Bound (UB) of the mean RIDIT value was calculated using equation 10, to check whether the value has not deviated significantly from 0.5.

Table 4. RIDIT Values for the Reference Data Set

MOE Code	ρ_i	LB	UB	Ranking	Broad Construct
WS	0.567007	0.672416	0.461598	22	Flow Characteristics (Capacity)
AM	0.58319	0.688599	0.477781	25	
Den	0.479803	0.585212	0.374394	11	
FR	0.568441	0.67385	0.463032	23	
Conn.	0.448047	0.553456	0.342637	9	Design (Built Environment)
P_signs	0.481738	0.587148	0.376329	13	
P_light	0.308118	0.413528	0.202709	2	
P_trees	0.541523	0.646933	0.436114	19	
P_shade	0.507957	0.613366	0.402548	16	
LU	0.596971	0.702381	0.491562	26	
Acc.	0.376685	0.482094	0.271275	7	
Cont.	0.48957	0.594979	0.384161	14	
P_Curb LA	0.363656	0.469065	0.258247	6	

MOE Code	ρ_i	LB	UB	Ranking	Broad Construct
W_SW	0.443011	0.54842	0.337601	8	
EW_SW	0.352043	0.457452	0.246634	5	
Buf	0.604982	0.710391	0.499573	27	User's Perception
P_Bar	0.555538	0.660947	0.450128	21	
Vol_Veh.	0.722079	0.827488	0.61667	31	
Speed_Veh.	0.582366	0.687775	0.476956	24	
Saf.	0.325627	0.431036	0.220218	3	
Sec.	0.325627	0.431036	0.220218	4	
Aest.	0.633638	0.739047	0.528229	28	
Com.	0.525125	0.630535	0.419716	17	
Con.	0.546487	0.651897	0.441078	20	
Dist.	0.678423	0.783832	0.573014	30	
P_SW	0.246237	0.351646	0.140827	1	
Sys_coh	0.648047	0.753456	0.542637	29	
P_park veh.	0.478978	0.584388	0.373569	10	
P_hawker	0.539642	0.645051	0.434232	18	
Obs.	0.481093	0.586502	0.375684	12	
S_Qual.	0.498351	0.603761	0.392942	15	

The MOEs in Table 4 are ranked based on the mean RIDIT score (ρ_i). As explained earlier in Section 3.4.2, the ranking is done based on a lower RIDIT score. Similar to the rankings obtained from TOPSIS, the same MOEs were assigned a higher ranking. It was observed that design elements (built walking environment) was found to be the most important among the three constructs as was mentioned earlier.

4.3. GRA Analysis

This analysis is similar to TOPSIS or RIDIT except for the fact that it is used on data sets with a lower sample value. The findings of this analysis are shown in Table 5.

Table 5. GRA Scores for the 31 MOEs

MOE Code	Γ_i	Ranking	Broad Construct
WS	0.635694	21	Flow Characteristics (Capacity)
AM	0.610494	25	
Den	0.693658	12	
FR	0.635333	22	
Conn.	0.731542	8	Design (Built Environment)
P_signs	0.697104	11	
P_light	0.837318	2	
P_trees	0.667841	17	
P_shade	0.686274	15	
LU	0.626075	23	
Acc.	0.766158	7	
Cont.	0.685421	16	
P_Curb LA	0.806194	5	
W_SW	0.723136	9	
EW_SW	0.802285	6	
Buf	0.591794	27	User's Perception
P_Bar	0.622985	24	
Vol_Veh.	0.512822	31	

MOE Code	Γ_i	Ranking	Broad Construct
Speed_Veh.	0.605324	26	
Saf.	0.8353	3	
Sec.	0.8353	4	
Aest.	0.585455	28	
Com.	0.649151	20	
Con.	0.655158	18	
Dist.	0.563185	30	
Sys_coh.	0.577217	29	
P_SW	0.903944	1	
P_park veh.	0.690029	13	
P_hawker	0.650465	19	
Obs.	0.706165	10	
S_Qual.	0.687913	14	

The Γi function is the Grey score in Table 5 and is similar to the *C** score in Table 3 for the TOPSIS analysis. As explained in Section 3.4.3, the higher rank is assigned to the MOE with a higher value of Γi score. Again, from this analysis, it is seen that there is a strong opinion of the experts to move towards the built walking environment of a sidewalk facility for assessing the PLOS.

4.4. Comparison of the three different rankings

A summary of the three different rankings is shown in Table 6. It is seen that there exists a strong correlation between the rankings of the three techniques as the ranks do not vary too much. It can thus be concluded that there is very low variation in the ranking from the different techniques. Spearman's rank order (ρ) correlation technique (Sharma, 2005) was used to find the correlation among the rankings of each pair of techniques and it was found to be statistically significant at the 95% confidence interval. The Spearman's ρbetween TOPSIS and RIDIT techniques ($\rho_{TOP-RID}$) = 0.969; similarly $\rho_{RID-GRA}$=0.986 and $\rho_{TOP-GRA}$= 0.964.

Since the rank correlation between the ratings of each method is very high, a single method (out of the three) cannot be selected to say that a certain set of rank is different from the other. Thus, mean ranking of the three methods can be safely assigned to the MOEs to reach a solitary ranking system, as shown in Table 6.

The line chart in Figure 5 is plotted to show the variation in individual MOE ranking across the three methods. A straight line for an MOE indicates no variation across the three methods. It was observed that there is low variation in the rankings across the methods, which accounts for the high ρ value.

An interesting observation can be drawn from Table 6 and Figure 5 — the top 15 MOEs of the initially selected 31 (about 50% of the total MOEs) fall under the broad construct of either the design (built environment) or the users' perception. Only one (Density, i.e. Den) out of the top 15 MOEs is in the broad construct of flow characteristics. In addition to this, the top four MOEs (i.e. Presence of Sidewalk, Presence of Street illumination, Safety and Security) were unanimously selected (refer Figure 5) and strongly hint toward the broad constructs of users' perception and design (built environment).

Table 6. Comparison of the Ranking

MOE Code	TOPSIS	RIDIT	GRA	Mean Ranking rounded off to the nearest integer	Broad Construct
WS	24	22	21	23	Flow Characteristics (Capacity)
AM	22	25	25	24	
Den	10	11	12	10	
FR	16	23	22	21	
P_signs	12	13	11	12	Design (Built Environment)
P_light	2	2	2	2	
P_trees	21	19	17	18	
P_shade	14	16	15	15	
W_SW	7	8	9	8	
EW_SW	5	5	6	5	
Conn.	9	9	8	9	
LU	26	26	23	26	
Acc.	6	7	7	7	
Cont.	18	14	16	16	
P_Curb LA	8	6	5	6	
Speed_Veh.	25	24	26	25	User's Perception
Saf.	3	3	3	3	
Sec.	4	4	4	4	
Aest.	29	28	28	28	
Com.	19	17	20	17	
Con.	20	20	18	19	
Dist.	30	30	30	30	
P_SW	1	1	1	1	
Sys_coh.	28	29	29	29	
P_park veh.	13	10	13	13	
P_hawker	23	18	19	20	
Obs.	11	12	10	11	
S_Qual.	15	15	14	14	

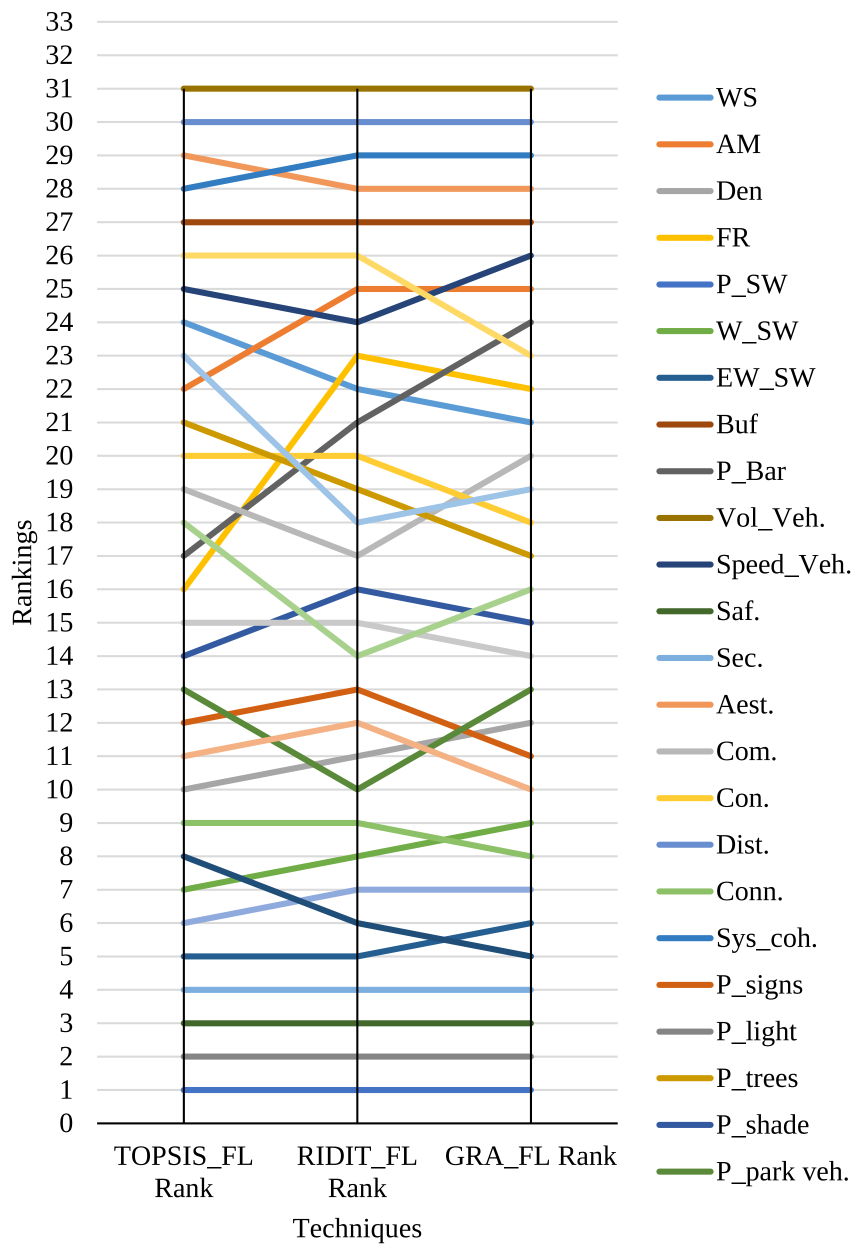


Figure 5. Graphical comparison of the rankings obtained by the three techniques using the Fuzzy Likert scale

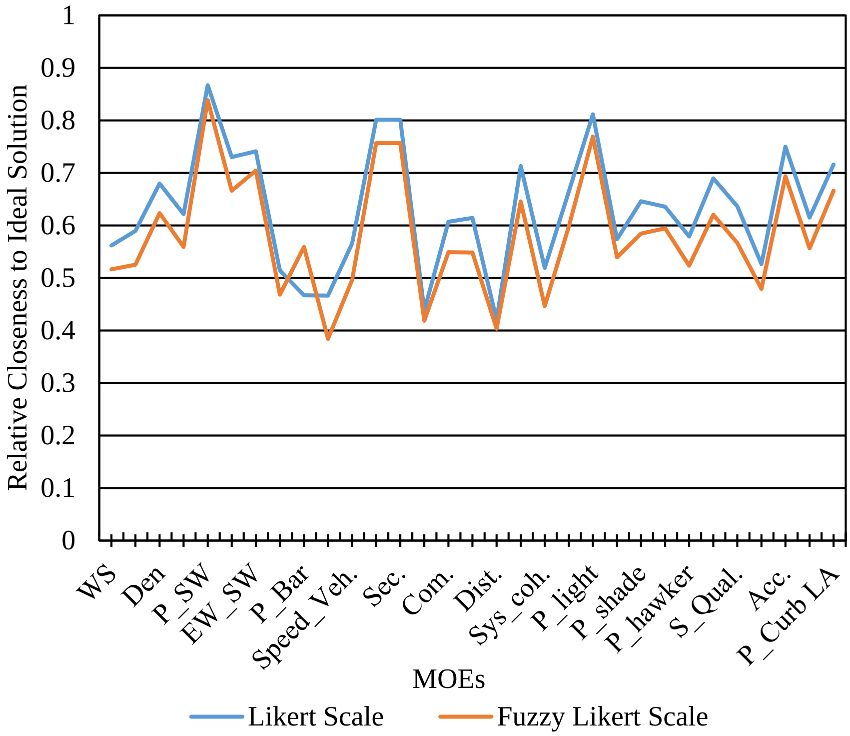
4.5. Comparison between the results using a Likert Scale and the Fuzzy Likert (FL) Scale

Effectiveness and usefulness of the FL scale in comparison to the ordinary Likert scale is presented in the following sub-sections.

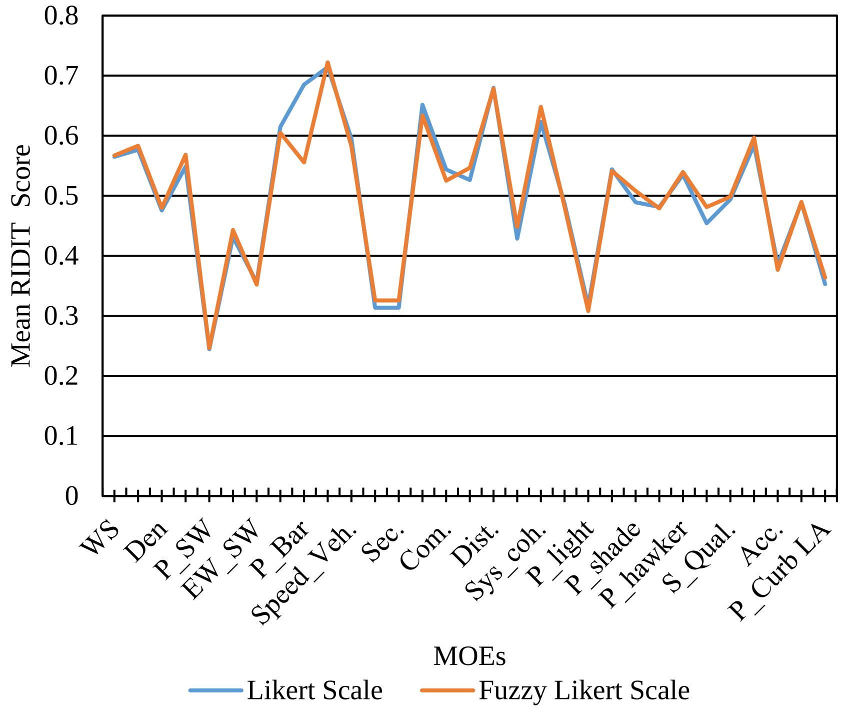
4.5.1 Difference in the estimation of the C^*, ρ_i and Γ_i for the three methods

As has been explained earlier in Section 3.4 — for the three methods of TOPSIS, RIDIT and GRA — specific metrics are earmarked for the purpose of ranking the alternatives. For TOPSIS, relative closeness to the ideal solution (C^*) is the metric on which the alternatives are ranked. Similarly, for

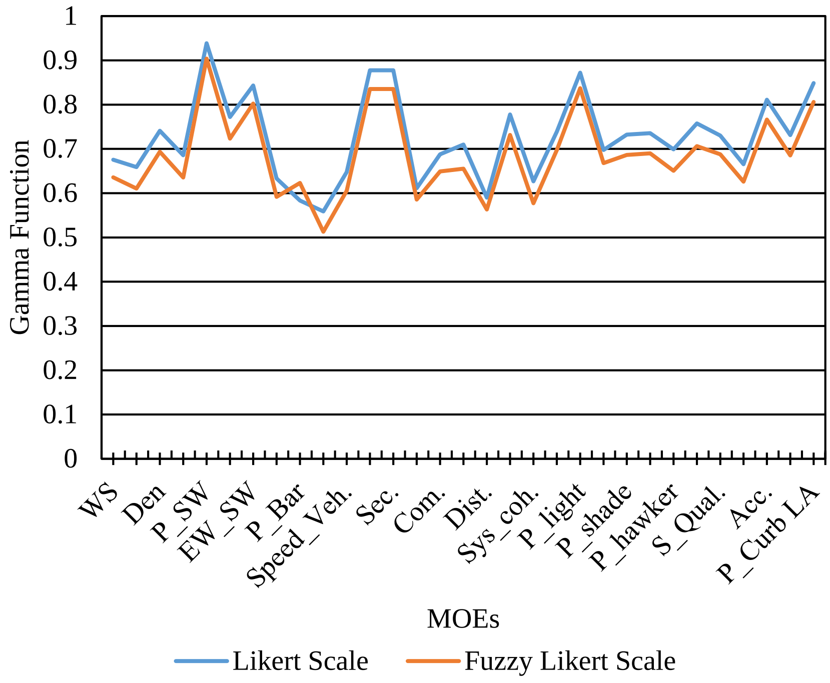
RIDIT and GRA, mean RIDIT score (ρ_i) and the gamma function (Γ_i) are the decision metrics for ranking, respectively. The higher the value of $C^*$and Γ_i, the higher is the rank of the alternative (i.e. the alternative with the highest C^*or Γ_i is ranked 1 for TOPSIS or RIDIT, respectively) and the lower the value of ρ_i, the higher is the rank of the alternative (i.e. the alternative with the lowest ρ_i is ranked 1 for GRA).



(a)



(b)



(c)

Figure 6. Fuzzy Likert vs Likert scale comparison using (a) TOPSIS; (b) RIDIT; (c) GRA

As seen from Figure 6(a), C^* obtained from the Likert scale are overestimated compared to the C^*obtained from the FL scale. This shows that there is a propensity for the Likert scale to over-estimate the relative closeness to the ideal solution. Again, from Figure 6(b) it is seen that ρ_i obtained from the Likert scale, either is underestimated or closely follows the ρ_i obtained from the FL scale. This happens because the most desirable MOE would have the lowest ρ_i. The same observation could be noted for Figure 6(c) where the Γ_i value from the Likert scale is overestimated compared to the Γ_i value obtained from the FL scale. Thus, it can be concluded that the Likert scale has a tendency to oversimplify these decision metrics (i.e. C^*, ρ_i, Γ_i) and the FL seems to give a more positive representation of the opinions relative to the actual scenario.

4.5.2 Variation in the ranking of MOEs across the three rating methods

Another important area that the FL scale has helped with in this study is the ability to consistently rank the topmost MOEs across the different methods. As per Figure 5, the top four MOE (i.e. presence of sidewalk, presence of street illumination, safety and security) are ranked consistently for the FL scale, whereas the rankings obtained from the Likert scale (Figure 7) are only consistent for the topmost factor (i.e. presence of sidewalk). Comparing Figures 5 and 7, it can be observed that the rankings obtained from the FL scale are much less variable compared to the Likert scale, as there are more straight lines (constant across the three methods) for individual MOEs.

Therefore, it can be said that use of the FL scale over the Likert scale in this study has thrown up new insights.

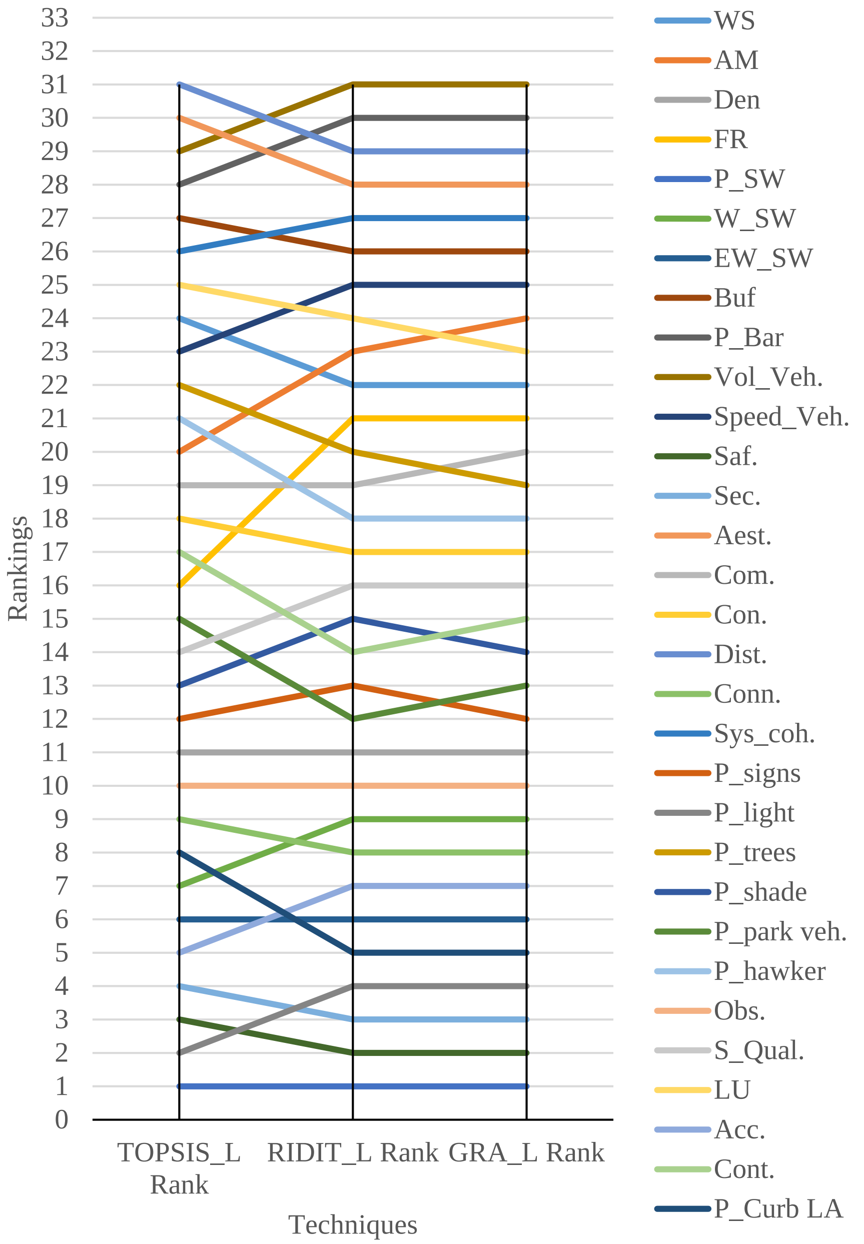


Figure 7. Graphical comparison of the rankings obtained by the three techniques using the Likert Scale

Accuracy assessment between Fuzzy Likert and the Likert Scale

Researchers (Clegg, 1998) have shown that the use of mean or standard deviation to assess the central tendency and the dispersion of a data set on ordinal Likert scales are not suitable where scores usually represent linguistic statements (Li, 2013). On the other hand, "consensus score" (refer equation 2 in Section 3.3) can appropriately measure the dispersion of a data set on ordinal scales, where equal intervals with a true zero point is not implied (Tastle, Russell, & Wierman, 2005; Tastle & Wierman, 2007). Therefore, "consensus score (Cns)" can be used as a reliable measure to compare the measurement accuracies of both Likert scales. Cns is a measure which shows the consensus of the experts on a particular MOE - the closer is the value of Cns to one, the higher is the consensus among experts.

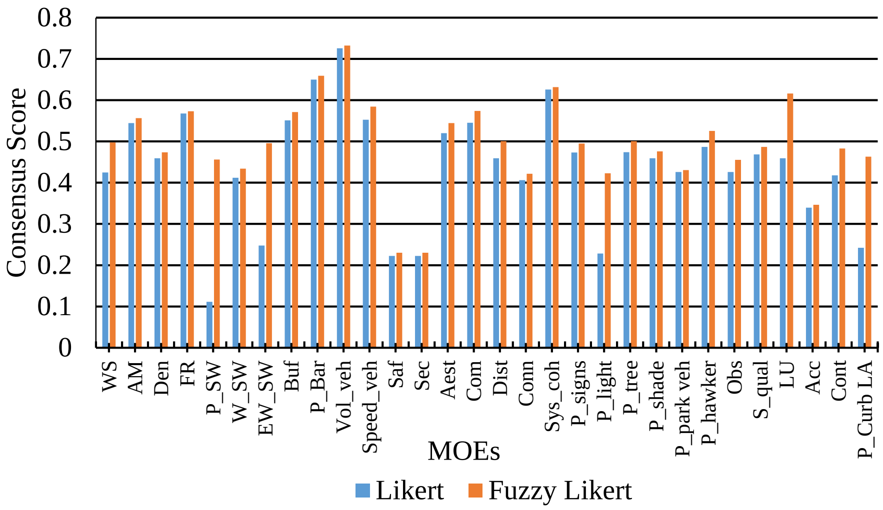


Figure 8. Consensus Score Cns for both the scales across all the MOEs

Figure 8 shows the plot of Cns for all the MOEs used in the study. It can be observed that all the Cns using the FL scale are higher than those using the Likert scale. The average Cns of all the MOEs using the Likert scale is 0.4383, whereas for the FL scale the value is 0.4956, indicating the ability of the FL scale to better express the consensus of the experts. The FL scale shows a better consensus because of the nature of the scale to accommodate the partial agreement feature. Since a Likert scale is discretised, it is unable to accommodate the responses properly, and therefore, more information is lost during measurement. Thus, the result suggests the FL scale to be more accurate than the Likert scale for ordinal datasets.

5. CONCLUSION

The very first conclusion that can be drawn from this study of FL scores using three different techniques is that the ranks obtained from the three different techniques are not too different from one another. This is reflected in the high Spearman's Rank correlation value due to which a mean ranking (round off to the nearest integer) for each MOE was assigned (Table 6). Following these ranking of MOEs, it could be seen that the first four MOE (as seen in Figure 5) rank unanimously through all three techniques. The first four MOEs include — *presence of sidewalk (*P_SW*), presence of street illumination (*P_light*), safety (*Saf.*)* and *comfort (*Com.*)* — all of them categorised under the broad construct of built environment and user's perception. Further, it was clear from the analysis that the experts deem built walking environment — like *width of sidewalk (*W_SW*)* and *effective width of sidewalk (*EW_SW) — and the users' perception of MOEs like *safety* (Saf.) and *comfort* (Com.) to be more important than the flow characteristics. It is seen that of the top 10 MOEs selected through this method, five are design or built environment MOEs, four are users' perception, and the remaining one belongs to the flow characteristics construct. This reinforces the fact that PLOS studies should not be assessed based on only one specific construct, but all three constructs, namely, the built walking environment, the users' perception and the flow characteristics (Kadali & Vedagiri, 2016; Landis et al., 2001). Studies like Cervero (2002) also confirm that design improvement or built environment improvement have more influence on people's decision to walk and has been considered a much smarter approach. Thus, it could be said that unlike previous studies (like HCM, 2000), experts are focussing less on the quantitative aspect of PLOS estimation and embracing the qualitative aspect of the same.

An important point that should be noted is the accuracy. The results of this study are based on the input from experts who have responded to an online questionnaire. The experts (Section 3.2) come from different areas of specialty — transportation, infrastructure design and urban planning. Since there is a huge variation in the expertise of specialists in this study, different experts might interpret and prioritise the given set of MOEs differently. For example, a transport professional might view high *pedestrian density* to be more important in the assessment of PLOS compared to an urban designer who may feel that higher density might dissuade people from walking. There may have been biases that might show up in the final rankings of the MOEs. Although it is desirable to have varied experts from different fields — the same can be also treated as a shortcoming of this research.

Regarding the usage of the Fuzzy-Likert scale for assessment of opinions instead of the Likert scale, ample evidence could be drawn from the analyses, which suggests that the FL scale is a much better option to collect ordinal scale data. This could be attributed to the nature of Fuzzy sets (Zadeh, 1965), which is instrumental in capturing the uncertainty of responses since it is not discrete unlike the Likert scale. It is observed that the mean consensus score for the experts across all the MOEs is 0.4383 when using a Likert scale, whereas there is an increase to 0.4956 for the same when using an FL scale. The accuracy in capturing the consensus is thus 13.08% more than the Likert scale. Thus, the use of the FL scale in collecting responses brings in more accuracy in the measurement process, and thereby increases its reliability as an analysis tool for ordinally rated datasets.

This study contributes in two ways — firstly it establishes the validity of using a different response measurement to capture responses more accurately, and secondly it establishes the need for considering the three broad constructs while estimating the PLOS of a sidewalk facility. Although the FL scale is already an established methodology by Li (2013), this study modifies the same methodology to take into account responses which might have an ambiguous conversion to FL scores from Likert scores. After conversion of these Likert scores to FL scores, the analysis results of TOPSIS, RIDIT and GRA were helpful in ascertaining the need of a PLOS that could outline the complete picture of the walking experience.

REFERENCES

Bandara, S., Wirasinghe, S. C., Gurofsky, D., & Chan, P. (1994). "Grade-Separated Pedestrian Circulation Systems". *Transportation Research Record*, *1438*, 59-59.

Boquet, Y. (2014). "Transportation and Sustainable Development in a Mid-Size French City, Dijon". *International Review for Spatial Planning and Sustainable Development*, *2*(2), 52-63.

Bross, I. D. J. (1958). "How to Use Ridit Analysis". *Biometrics*, *14*(1), 18-38.

Cervero, R. (2002). "Built Environments and Mode Choice: Toward a Normative Framework". *Transportation Research Part D: Transport and Environment*, *7*(4), 265-284.

City of Fort Collins. (2002). "Multimodal Transportation Level of Service Manual-Fort Collins". Fort Collins:

Clegg, C. (1998). *Simple Statistics.* Cambridge: Cambridge University Press.

Dandan, T., Wei, W., Jian, L., & Yang, B. (2007). "Research on Methods of Assessing Pedestrian Level of Service for Sidewalk". *Journal of Transportation Systems Engineering and Information Technology*, *7*(5), 74-79.

Davis, D. G., & Braaksma, J. P. (1987). "Level-of-Service Standards for Platooning Pedestrians in Transportation Terminals". *ITE Journal (Institute of Transportation Engineers)*, *57*(4), 31-35.

Deng, J. L. (1989). "Introduction to Grey System Theory". *The Journal of Grey System*, *1*(1), 1-24.

Dixon, L. B. (1996). "Bicycle and Pedestrian Level-of-Service Performance Measures and Standards for Congestion Management Systems". *Transportation Research Record: Journal of the Transportation Research Board*, *1538*(1), 1-9.

Fruin, J. J. (1971). "Designing for Pedestrians: A Level-of-Service Concept". Proceedings of 50th Annual Meeting of the Highway Research Board, Washington DC, US. Retrieved from http://onlinepubs.trb.org/Onlinepubs/hrr/1971/355/355-001.pdf.

Gallin, N. (2001). "Quantifying Pedestrian Friendliness--Guidelines for Assessing Pedestrian Level of Service". *Road & Transport Research*, *10*(1), 47-55.

Gil, M. Á., & González-Rodríguez, G. (2012). "Fuzzy Vs. Likert Scale in Statistics". In E., T., P., B., L., M., & J., K. (Eds.), *Combining Experimentation and Theory* (pp. 407-420). Berlin, Heidelberg: Springer.

Hwang, C. L., & Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications.* New York: Springer-Verlag.

Jaskiewicz, F. (2000). "Pedestrian Level of Service Based on Trip Quality". *TRB Circular E-C019: Urban Street Symposium*, *G-1*, 1-14. Retrieved from http://onlinepubs.trb.org/onlinepubs/circulars/ec019/Ec019_g1.pdf.

Jensen, S. U. (2007). "Pedestrian and Bicyclist Level of Service on Roadway Segments". *Transportation Research Record*, *2031*(1), 43-51.

Kadali, B. R., & Vedagiri, P. (2016). "Review of Pedestrian Level of Service: Perspective in Developing Countries". *Transportation Research Record: Journal of the Transportation Research Board*, *2581*(1), 37-47.

Khisty, C. J. (1994). "Evaluation of Pedestrian Facilities: Beyond the Level-of-Service Concept". *Transportation Research Record No. 1438, Research Issues on Bicycling, Pedestrians, and Older Drivers*, 45-50.

Kim, S., Choi, J., Kim, S., & Tay, R. (2014). "Personal Space, Evasive Movement and Pedestrian Level of Service". *Journal of advanced transportation*, *48*(6), 673-684.

Kotkar, K., Rastogi, R., & Chandra, S. (2010). "Pedestrian Flow Characteristics in Mixed Flow Conditions". *Journal of Urban Planning and Development, ASCE*, *136*(3), 23-33.

Landis, B. W., Vattikuti, V. R., Ottenberg, R. M., McLeod, D. S., & Guttenplan, M. (2001). "Modeling the Roadside Walking Environment: Pedestrian Level of Service". *Transportation research record*, *1773*(1), 82-88.

Li, Q. (2013). "A Novel Likert Scale Based on Fuzzy Sets Theory". *Expert Systems with Applications*, *40*(5), 1609-1618.

Lopez, A. (2006). "Assessment of Measures to Ease Pedestrian Congestion". Proceedings of Association for European Transport and contributors. Retrieved from https://stuff.mit.edu/afs/athena/course/11/11.951/oldstuff/albacete/Other_Documents/Europe%20Transport%20Conference/planning_for_sustainab/assessment_of_meas1474.pdf.

Miller, J. S., Bigelow, J. A., & Garber, N. J. (2000). "Calibrating Pedestrian Level-of-Service Metrics with 3-D Visualization". *Transportation Research Record: Journal of the Transportation Research Board*, *1705*(1), 9-15.

Muraleetharan, T., Adachi, T., Uchida, K.-e., Hagiwara, T., & Kagaya, S. (2003). "A Study on Evaluation of Pedestrian Level of Service Along Sidewalks and at Intersections Using Conjoint Analysis". Proceedings of Annual Meeting of Infrastructure Planning, Japanese Society of Civil Engineers (JSCE) Toyohashi, Japan, pp. 5-8.

Petritsch, T. A., Landis, B. W., McLeod, P. S., Huang, H. F., Challa, S., & Guttenplan, M. (2005). "Level-of-Service Model for Pedestrians at Signalized Intersections". *Transportation Research Record*, *1939*(1), 54-62.

Polus, A., Schofer, J. L., & Ushpiz, A. (1983). "Pedestrian Flow and Level of Service". *Journal of Transportation Engineering*, *109*(1), 46-56.

Pushkarev, B., & Zupan, J. M. (1975). *Urban Space for Pedestrians: A Report of the Regional Plan Association.* Cambridge, MA: MIT Press.

Rastogi, R., Ilango, T., & Chandra, S. (2013). "Pedestrian Flow Characteristics for Different Pedestrian Facilities and Situations". *European Transport / Trasporti Europei*, (53), Paper 5.

Ross, T. J. (1995). *Fuzzy Logic with Engineering Applications.* New Delhi John Wiley & Sons.

Sadhukhan, S., Banerjee, U. K., & Maitra, B. (2015). "Commuters' Perception Towards Transfer Facility Attributes in and around Metro Stations: Experience in Kolkata". *Journal of urban planning and development*, *141*(4). doi: https://doi.org/10.1061/(ASCE)UP.1943-5444.0000243.

Sahani, R., Ojha, A., & Bhuyan, P. K. (2017). "Service Levels of Sidewalks for Pedestrians under Mixed Traffic Environment Using Genetic Programming Clustering". *KSCE Journal of Civil Engineering*, *21*(7), 2879-2887.

Sahani, R., Praveena, D., & Bhuyan, P. K. (2016). "Use of Multinomial Logit Model in Evaluation of Service Levels of Pedestrian Facilities". Proceedings of International Conference on Transportation Planning and Implementation Methodologies for Developing Countries(12th TPMDC), Mumbai, India.

Sarkar, S. (1993). "Determination of Service Levels for Pedestrians, with European Examples". *Transportation Research Record: Journal of the Transportation Research Board*, *1405*, 35-42.

Sharma, A. K. (2005). *Text Book of Correlations and Regression.* Discovery Publishing House.

Singh, K., & Jain, P. K. (2011). "Methods of Assessing Pedestrian Level of Service". *Journal of Engineering Research and Studies*, *2*(1), 116-124.

Sisiopiku, V. P., Byrd, J., & Chittoor, A. (2007). "Application of Level-of-Service Methods for Evaluation of Operations at Pedestrian Facilities". *Transportation Research Record: Journal of the Transportation Research Board*, *2002*(1), 117-124.

Tanaboriboon, Y., & Guyano, J. A. (1989). "Level-of-Service Standards for Pedestrian Facilities in Bangkok: A Case Study". *ITE journal*, *59*(11), 39-41.

Tastle, W. J., Russell, J., & Wierman, M. J. (2005). "A New Measure to Analyze Student Performance Using the Likert Scale". Proceedings of 22nd Information Systems Education Conference (ISECON), Columbus OH, pp. 1-7.

Tastle, W. J., & Wierman, M. J. (2007). "Consensus and Dissention: A Measure of Ordinal Dispersion". *International Journal of Approximate Reasoning*, *45*(3), 531-545.

Transportation Research Board. (2000). "Highway Capacity Manual". Washington, DC: Transportation Research Board, National Research Council.

Transportation Research Board. (2008). "National Co-Operation Highway Research Program (R-616)". Washington, DC: Transportation Research Board, National Research Council.

Transportation Research Board. (2010). "Highway Capacity Manual". Washington, DC: Transportation Research Board, National Research Council.

Wu, C.-H. (2007). "On the Application of Grey Relational Analysis and Ridit Analysis to Likert Scale Surveys". *International Mathematical Forum*, *2*(14), 675-687.

Zadeh, L. A. (1965). "Fuzzy Sets". *Information and Control*, *8*(3), 338-353.