Exploring effective micro-level items for evaluating inclusive walking facilities on urban streets (applied in Johor Bahru, Malaysia)

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ABSTRACT

Modern cities try to provide enough facilities for inclusive and pedestrian-friendly streets. Evaluating and designing models that consider a wide range of street users, including disabled people, can help urban planners to design these inclusive streets. The results of existing (but limited) studies evaluating street conditions for pedestrians do not include a wide range of street users. Therefore, this paper seeks to propose a new model for evaluating and improving urban streets, focusing on inclusive pedestrian facilities. This study introduces pedestrian mobility indicators using advanced design guidelines, existing literature and expert interviews. These indicators are evaluated by exploratory factor analysis (EFA) to find underlying patterns. Levels of association between observed and latent variables are tested by confirmatory factor analysis (CFA) and second-order confirmatory factor analysis (SOCFA). Structural equation modelling (SEM) is used to perform the CFA and SOCFA analyses. A questionnaire was used to collect data from 599 participants randomly selected from Setia Tropika residents (Johor, Malaysia). The resultant factor loading values are used as weights in an analytical points-based system, comparing existing facilities to a standard to estimate street facilities and infrastructure levels of service for pedestrians. This pedestrian level of service (PLOS) can be applied to various urban streets around the world, but in this study a street in Malaysia is evaluated using this method to check the accuracy of the proposed PLOS model. Existing street problems and potential improvements can be identified by this model.

1. Introduction

Although there are numerous studies regarding different aspects of sustainability (e.g., energy consumption, biodiversity, water and air pollution, fair distribution of income, etc.), sustainable living has received less attention (Cubukcu, 2013). Walking as part of a sustainable lifestyle can be categorized as sustainable living, which aims to reduce the effects of negative externalities to modern lifestyles, such as obesity and overweight (Larsen, 2014; McDonald, 2007). Various health and urban planning studies (e.g. Bader et al., 2015; De Vries, Bakker, Van Mechelen, & Hopman-Rock, 2007; Rodriguez, Aytur, Forsyth, Oakes, & Clifton, 2008) show that the availability of walking facilities is positively related to walking and physical activity rates.

In addition, there is growing concern over negative externalities associated with private motorized trips, such as air pollution, fuel consumption and safety problems (Moeinaddini, Asadi-Shekari, & Zaly Shah, 2014; Moeinaddini, Asadi-Shekari, & Zaly Shah, 2014; Moeinaddini, Asadi-Shekari, & Zaly Shah, 2015; Moeinaddini, Asadi-Shekari, & Zaly Shah, 2015). If automobile users shift to walking for short trips, the considerable amount of emissions and fuel consumption per mile associated with short trips can be reduced (Holbrow, 2013). A two to four per cent reduction in fuel consumption can be achieved if only one per cent of automobile users shift to walking (Litman, 2012). Walking is the primary mode of transportation for people around the world. This mode is flexible and has health benefits (Asadi-Shekari, Moeinaddini, & Zaly Shah, 2014; Otak, 1997; Southworth, 2005; Tan, Wang, Lu, & Bian, 2007). Walking is also the most affordable means of transportation since it is cheap and needs only some basic

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infrastructures (Aghaabbasi, Moeinaddini, Shah, & Asadi-Shekari, 2017 and Aghaabbasi, Moeinaddini, Shah, & Asadi-Shekari, 2018; Asadi-Shekari, Moeinaddini, & Zaly Shah, 2015; Asadi-Shekari, Moeinaddini, & Zaly Shah, 2015).

Despite the vast benefits of walking, most planning efforts tend to pay noticeably greater attention to motorized transportation. Findings from recent studies show that improvement of operational characteristics and the pedestrian environment can encourage people to walk, and directly influence people's quality of life, safety (Ewing, Handy, Brownson, Clemente, & Winston, 2006; Mehta, 2008; Saelens, Sallis, & Frank, 2003) and road congestion (Elias & Shiftan, 2012). Sidewalk facility enhancements that consider a wide range of users lead to higher levels of satisfaction among people with diverse abilities (Asadi-Shekari et al., 2014).

By revealing the health and social benefits of walking in recent years, the need to create satisfactory walking environments has been stressed. People's satisfaction with their walking environment motivates them to choose walking as a habitual behaviour (Ettema et al., 2011). Creating a pleasant pedestrian environment can be achieved through sustained assessment and inspection of sidewalk facilities. However, assessing the pedestrian environment is more complicated than vehicle roadways (Landis, Vattikuti, Ottenberg, McLeod, & Guttenplan, 2001).

'Level of service' (LOS) is an instrument for assessing the overall quality of service, street furnishing and infrastructure (Asadi-Shekari et al., 2014; Moeinaddini, Asadi-Shekari, Ismail, & Zaly Shah, 2013). The pedestrian level of service (PLOS) is necessary for improving existing infrastructure and guiding new investments (Christopoulou & Pitsiava-Latinopoulou, 2012). It helps designers and planners to identify shortcomings in pedestrian street environments and can suggest improvements for solving the problems. In other words, PLOS assesses the quality of street conditions for pedestrians.

In addition to pedestrian flow and volume (Fruin, 1971; HCM, 2000; Tanaboriboon & Guyano, 1989), current PLOS methods assess different walking facilities, such as curb ramps, tactile pavements, accessible drinking fountains (Aghaabbasi et al., 2017; Asadi-Shekari et al., 2015a, 2015b; Asadi-Shekari et al., 2014), lighting, bollards, seating areas, the landscape, trees, driveways (Aghaabbasi et al., 2017; Clifton, Livi Smith, & Rodriguez, 2007; Kihl, Brennan, Gabhawala, List, & Mittal, 2005), toilets and rubbish bins (Aghaabbasi et al., 2017; Cunningham, Michael, Farquhar, & Lapidus, 2005; Rahimiashtiani & Ujang, 2013) in addition to maintenance, slopes and natural barriers (Clifton et al., 2007; Williams et al., 2005).

Some studies have defined the PLOS as a classification problem. For example, Sahani and Kumar (2017) used three methods of clustering, including affinity propagation, self-organizing maps in artificial neural networks and genetic algorithm-fuzzy (GA-Fuzzy) methods, to find the most suitable clustering. They found that the GA-Fuzzy is the most suitable one. However, this study just focused on capacity based on related factors, such as pedestrian space, flow, volume to capacity ratio and pedestrian speed. In addition, these studies focus on behavioural analysis rather than the main aim of PLOS, which is helping to identify shortcomings and suggesting improvements.

PLOS methods can be classified into two main types (Asadi-Shekari, Moeinaddini, & Zaly Shah, 2013; Asadi-Shekari, Moeinaddini, & Zaly Shah, 2013). The first type includes capacity-based models that focus on sidewalk capacity, pedestrian flow and volume (e.g., Fruin, 1971; HCM, 2000; Tanaboriboon & Guyano, 1989). The second type includes roadway characteristics-based models that focus on design factors and pedestrian facilities (e.g., Asadi-Shekari et al., 2013a, 2013b; Asadi-Shekari et al., 2014; Khisty, 1994; Landis et al., 2001; Lautso & Murole, 1974; Sarkar, 1993; Tan et al., 2007). The first approach has been criticized in various studies since these studies treat pedestrians like cars and do not consider pedestrians as special users with particular needs (Asadi-Shekari et al., 2013a, 2013b). In addition, a considerable number of studies have focused on evaluating the capacity of sidewalks.

Therefore, this study pays more attention to the second approach than the first one. Moreover, characteristics-based models consider micro design factors, such as sidewalk facilities, which have an important impact on pedestrian perceptions of their walking environment. This approach focuses on how safe/secure, attractive and comfortable a sidewalk segment or intersection is for pedestrians.

The first attempt to develop a PLOS model was organized by Fruin (1971). This model is based on pedestrian volume and sidewalk capacity. Tanaboriboon and Guyano (1989) followed Fruin's idea to assess the PLOS of walkways in Bangkok. Their PLOS model is based on area occupancy per person. These primary types of PLOS models exclude micro-level design factors from the assessment. Furthermore, sidewalk capacity-based PLOS models like HCM (2000) do not consider other important factors, such as street furniture. In addition, these models treat pedestrians like vehicles (Asadi-Shekari et al., 2013a, 2013b).

Pedestrian perceptions and expectations are other important factors in some of the PLOS studies. Kang and Xiong (2013) found pedestrian flow rates to be the most effective factor for PLOS perception, although other factors, such as sidewalk width, separation from traffic and on-street parking, also have significant effects on PLOS perception in this study. Kadali and Vedagiri (2015) also concluded that perceived PLOS at un-signalized mid-block crosswalks can be affected by perceived safety, crossing difficulty, median width and land-use conditions, in addition to vehicular traffic-related factors, such as the number of vehicles encountered and number of lanes. However, many other factors (such as comfort, accessibility and sidewalk facilities) can affect PLOS perception.

The need to develop PLOS models that consider micro-level design factors has led to the introduction of characteristics-based PLOS models, which consider pedestrian facilities and infrastructure providing comfortable, secure, safe and convenient walking trips. Dixon's points-based rating system (1996) emphasizes the safety of pedestrians by considering factors like basic pedestrian facilities, amenities, conflicts and multiple travel options. The weights in this model are chosen arbitrarily. Miller, Bigelow, and Garber (2000) proposed the same idea (a points system) to assess the PLOS by using a simulation method (3-dimentional visualization technique) to collect data. However, the limited range of facilities and street users make the results of these types of studies insufficient for a suitable evaluation model for inclusive streets.

Landis et al. (2001) proposed a PLOS model by considering pedestrian perceptions of the safety of roadside walking environments. In this method, factors significantly affecting pedestrian perceptions have been identified using an ordinary squares regression. Identified factors include lateral separation of pedestrians from motorized vehicles, the total number of lanes, motorized vehicle volume, motorized vehicle speed and sidewalk width. Although this PLOS method is commonly used as a reference for various studies, this model considers a limited number of factors, which may not convey the complexity of streets on one side of the equation, and provision for safety and convenience on the other, mainly because of regression model limitations.

Jensen (2007) developed a PLOS model by using video clips to identify the factors that affect pedestrian satisfaction regarding roadway segments. A logit model is used to estimate the PLOS. Factors like the type of walking area, average speed of motor vehicles and presence of medians have been used in this model. In comparison with Landis et al. (2001), Jensen (2007) used more indicators to assess the PLOS. However, these indicators do not include a wide range of users (e.g., disabled people). Asadi-Shekari et al. (2013a) proposed a PLOS model that considers micro-level design factors for a wide range of users, including disabled people. The weights of the indicators in this study are estimated based on the importance of factors in different guidelines. Therefore, pedestrian perceptions of their environment are excluded from this PLOS model.

In recent years, Google tools have been applied in pedestrian assessment studies (Bader et al., 2015; Griew et al., 2013) to reduce the

audit cost and time. Some efforts have also been made to assess the feasibility of these tools (Aghaabbasi, Moeinaddini, Shah, Asadi-Shekari, & Kermani, 2018; Bethlehem et al., 2014; Kelly, Wilson, Baker, Miller, & Schootman, 2013; Phillips et al., 2017; Vanwolleghem, Van Dyck, Ducheyne, De Bourdeaudhuij, & Cardon, 2014; Wu et al., 2014; Zhua et al., 2017). Most of these studies mention that applying virtual assessment for detailed attributes and facilities remains time-consuming and sometimes impossible.

Existing PLOS methods lack reliable measures and assessment tools for pedestrians with various abilities (Asadi-Shekari et al., 2013b). Existing models cannot be used to evaluate street conditions for various users. For instance, many of the previous PLOS models assumed that pedestrians did not have a disability (Asadi-Shekari et al., 2013a). In addition, although lots of existing PLOS models focus on a macro-scale view (e.g., Jaskiewicz, 1999; Muraleetharan, Adachi, Hagiwara, & Kagaya, 2005; Petritsch et al., 2006), micro design factors are more important for identification of the quality of the walking environment (Southworth, 2005). Therefore, this study seeks to develop innovative PLOS models, which explain and evaluate inclusive streets for walking, focusing on universal micro-level design factors for a wide range of street users, in particular disabled people, while considering pedestrian perceptions of their environment.

2. Method

The majority of pedestrian facilities and the standards needed to ensure that sidewalks provide inclusive walking conditions, are identified by reviewing advanced guidelines, current literature and expert interviews. This reviewing process aimed to find new indicators and was stopped when all indicators became repeated. The final list of indicators identified in the reviewing process was presented at a meeting of experts, including architects, urban planners and transport planners, to ensure that all relevant indicators were present in the final list.

These indicators were then used to prepare a questionnaire for data collection, focusing on the importance of these indicators for inclusive pedestrian-friendly streets. The questionnaire has two main parts. The first part relates to personal information and socio-demographic status, and the second part includes the level of importance for each indicator. Respondents can rate the indicators and facilities from least important to extremely important using a 5-point rating system. A total of 599 respondents, who were living in the Setia Tropika district, were randomly selected. This district is a new residential area in Johor, Malaysia. Johor state is very close to Singapore and is located in southern Malaysia.

In the first step, principal axis factor (PAF) analysis with a varimax rotation is used, a common method for exploratory factor analysis (EFA), to find underlying patterns among items in the questionnaire. The Kaiser-Meyer-Olkin (KMO) is used to test sampling adequacy. The minimum acceptable value is 0.70 (Hair et al., 2014). Cronbach's alpha value also tests reliability based on inter-correlations and the minimum acceptable value is 0.70 (Hair et al., 2014). Results of the varimax rotation can show underlying patterns when loadings less than 0.40 are excluded.

In the second step, confirmatory factor analysis (CFA) is used to determine the relationships between observed variables and latent variables (underlying patterns that are achieved in the first step). To do this, a path diagram, which is common practice in structural equation models (SEM), is applied. This diagram includes rectangles or squares that represent observed variables; elliptics or ovals and circles that represent latent variables; and circles with a single-headed arrow that represents error terms. The acceptable level of association to extract significant factors is defined by squared factor loading values more than 0.40 and the maximum likelihood (ML) technique is used to estimate the parameters. Common CFA fitting tests are used to test the fitness of the model, such as the chi-square test (X2) and normed chi-square (X2/df); goodness-of-fit index (GFI) and adjusted goodness-of-fit index

(AGFI); root mean square error of approximation (RMSEA) and comparative fit index (CFI).

In the third step, second order confirmatory factor analysis (SOCFA) is used to determine the relationships between latent variables (underlying patterns that are achieved in PAF analysis) and the main latent variable (inclusive streets for walking). The acceptable level of association and model fitting tests are similar to CFA. The results of SOCFA can be used to identify the weight of each latent variable and observed variable when explaining inclusive streets for walking. The resulting factor loading values can be used as weights to estimate street facilities and infrastructure levels of service for pedestrians. Mathematically, this pedestrian level of service (PLOS) can be defined as follows: (refer to Eq. (1)):

$$\text{PLOS} = \sum_{i=1}^{n} W_{lv_i} \times PLOS_{lv_i} \tag{1}$$

where: $PLOS$ = pedestrian level of service, W = weight and lv_i = latent variables.

Each underlying pattern (latent variable) does not have the same effects on the proposed PLOS. Therefore, each one can have a specific coefficient (weight) based on its association with inclusive streets for walking. The importance and priority of each latent variable is illustrated by its coefficient or weight, and factor loading value is used to represent this weight. The same process can be used to define PLOS for each underlying pattern or latent variable (refer to Eq. (2)):

$$\text{PLOS}_{lv_i} = \sum_{j=1}^{n} W_{ov_j} \times S_{ov_j} \tag{2}$$

where: PLOS = pedestrian level of service, lv_i = latent variables, W = weight, S = score and ov_j = observed variables for related latent variable.

Each observed variable does not have the same effects on the proposed PLOS for the latent variables. Therefore, each one can have a specific coefficient or weight based on its association with inclusive streets for walking and factor loading value is used to represent this weight. S is a score between 0 and 1. This score can be achieved by comparing the existing condition with the standard condition mentioned in advanced guidelines and current literature. Therefore, this study also reviews standards for various facilities in different conditions. This reviewing process was also based on finding new standards and was stopped when all standards became repeated. For the standards that are different in various guidelines and studies, the most complete and pedestrian-friendly ones are selected. Standards from various guidelines are also combined to produce more complete and pedestrian-friendly standards. Appendix A indicates the standards collected for significant street factors, which are evaluated by the proposed PLOS model in this study.

Table 1
Rotated factor matrix that represents inclusive streets for walking.

	Factor		
	1	2	3
1 Curb ramp	0.612		
2 Bollard	0.552		
3 Driveway	0.498		
4 Ramp	0.468		
5 Tactile pavement	0.466		
6 Width of the sidewalk	0.451		
7 Surface material	0.450		
8 Lighting		0.679	
9 Landscape and tree		0.641	
10 Sitting area		0.522	
11 Toilet			0.764
12 Trash receptacles			0.619
13 Drinking Fountain			0.492
14 Elevator			0.464
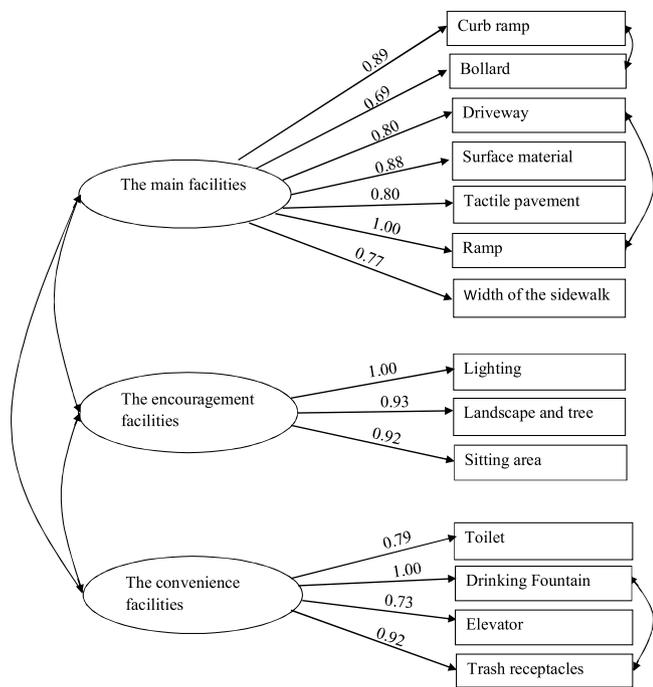
Fig. 1. Final CFA model that represents inclusive streets for walking model.

Table 2
The model fitting indices.

Model indices	Default model	Saturated model	Independence model
CMIN	247.756	0	2462.454
df	71	0	91
p	0.0001	–	0.0001
CMIN/*df*	3.490	–	27.060
GFI	0.944	1.000	0.445
AGFI	0.918	–	0.360
NFI	0.899	1.000	0.000
TLI	0.904	–	0.000
CFI	0.925	1.000	0.000
RMSEA	0.064	–	0.209

CMIN = Chi-square, *df* = degree of freedom, *p* = p-value for chi-square test, CMIN/*df* = the Normed chi-square, GFI = Goodness-of-Fit index, AGFI = Adjusted Goodness-of-Fit Index, NFI = Normed Fit Index, TLI = Tucker-Lewis Index, CFI = Comparative Fit Index, RMSE = Root Mean Square Error of Approximation.

S can be 0 for existing conditions that completely fail to fulfil the standards. This score can be 1 when conditions completely fulfil the standards. There are also some scores between 0 and 1 when the fitness between existing conditions and standards is semi-complete. This points system (comparison with standards) is used in various scoring methods and a similar scoring method for PLOS has been used by Asadi-Shekari et al. (2013a, 2014, 2015b). Appendix B shows the process of scoring and comparing existing conditions with standards for each *S*. The maximum score for each *S* is 1. Therefore, the PLOS percentage that is

the percentage of existing PLOS of the ideal PLOS (all scores are equal to 1) for the proposed PLOS can be defined as follows: (refer to Eqs. (3) and (4)):

$$PLOS\% = \frac{\sum_{i=1}^{n} W_{lv_i} \times PLOS_{lv_i}\%}{\sum_{i=1}^{n} W_{lv_i} \times 100} \times 100 \quad (3)$$

where: PLOS% = pedestrian level of service percentage, lv_i = latent variables, W = weight, PLOS $_{lv_i}$ % = pedestrian level of service percentage for latent variables.

$$PLOS_{lv_i}\% = \frac{PLOS_{lv_i}}{\sum_{j=1}^{n} W_{ov_j}} \times 100 \quad (4)$$

where: PLOS $_{lv_i}$ % = pedestrian level of service percentage for latent variables, lv_i = latent variables, W = weight, ov_j = observed variables for related latent variable.

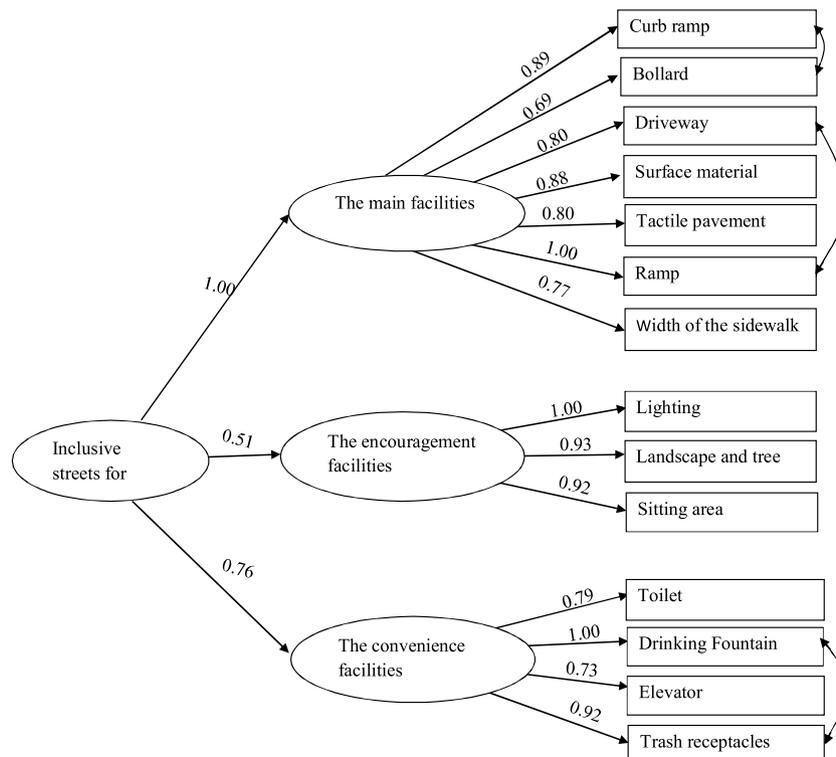Most level-of-service (LOS) studies use some rating system from 0 to

Fig. 2. Final SOCFA model that represents inclusive streets for walking model.

100 or A to F to make the results more understandable (e.g., Fruin, 1971; Sarkar, 1993; Dixon, 1996; Landis et al., 2001; Sarkar, 2002; Jensen, 2007; Asadi-Shekari et al., 2013a, 2014). PLOS A (a PLOS percentage between 80 and 100) shows the highest fitness with the standards and indicates pedestrian-friendly conditions. PLOS B (a PLOS percentage between 60 and 79) shows that the existing conditions are acceptable, but some improvements are required. PLOS C (a PLOS percentage between 40 and 59) indicates that the street requires more improvements. PLOS D (a PLOS percentage between 20 and 39) means the street requires considerable improvements. PLOS E (a PLOS percentage between 1 and 19) shows an unpleasant level of service for pedestrians and PLOS F (PLOS percentage = 0) indicates that there are no standard pedestrian facilities on the street.

3. Results

Different urban streets can be evaluated by this PLOS model since the indicators and standards are selected from advanced guidelines and current literature, regardless of the context effects. The universal micro-level design allows implementation of this method in various urban streets in different cities. However, the coefficients (weights) that are estimated by SEM can be used to localize the proposed PLOS.

The street used in this research to test the proposed PLOS is a collector street in the Setia Tropika area of Johor Bahru, Malaysia, which is a new residential area with more pedestrian facilities than similar areas in Johor Bahru. Pedestrian facilities evaluated in this area include the facilities on Main Street in Setia Tropika. The street segment evaluated is 1790 m long. This length can be used to represent the typical range of pedestrian facilities on this street.

Table 1 shows the results of a PAF analysis with a varimax rotation for the Likert scale questions in the questionnaire, while the KMO value (0.875) and Cronbach's alpha value (0.848) are at an acceptable level. Table 1 shows that seven items loaded onto the first factor. Since most of these items are related to the basic facilities needed for walking on inclusive streets, the first factor is labelled 'main facilities'. Three items loaded onto factor number two. Brighter levels of light can increase feelings of safety and encourage walking at night. Lighting in this study is related to the pedestrian lighting scale, which is added to the usual streetlighting to give brighter levels of light for pedestrians at night. This factor, in addition to other walking 'encouragement' factors (such as seating areas, the landscape and trees) can be categorized as encouragement facilities. Therefore, the second factor is labelled 'encouragement facilities'. Four items loaded onto the last factor. Since most of these items are related to the facilities needed for convenient walking, the last factor is labelled 'convenience facilities'.

CFA is used to determine the relationships between observed variables and underlying patterns (factors one, two and three) that are achieved from PAF analysis (see Table 1). Fig. 1 presents the final CFA model constructed for inclusive pedestrian-friendly streets. SOCFA is used to determine the relationships between latent variables (the underlying patterns that are factors one, two and three) and the main latent variable (inclusive streets for walking). Fig. 2 presents the final constructed SOCFA model, which explains inclusive streets for walking. Table 2 shows the goodness-of-fit tests for the proposed models. The results of SOCFA can be used to identify the weight of each latent variable and observed variable when explaining inclusive streets for walking. Table 3 shows that all the model estimates are statistically significant at a level of 0.001.

The importance and priority of latent variables and observed variables can be illustrated by their weights, and factor loading values (see Fig. 2) are used to represent these weights. Based on the proposed equations, scores for the observed variables are needed to estimate related PLOSs in addition to the estimated weights. The length of the street selected for this research is 1722 m on one side, without considering intersections. A sidewalk is provided along this section of the street and on the opposite side. Setia Tropika has various widths of footpath pavement. The width of the footpath pavement is 1.18 m for 490 m of the street and 1.5 m for 1232 m of the street. These widths are the same on the opposite side so, in total, the footpath pavement is 1.18 m wide for 980 m of the street and 1.5 m wide for 2464 m. Both of these widths are less than the minimum standard width, which is 1.8 m. However, they have a standard footpath pavement. Appendix B shows the method of comparing existing conditions with the standards to achieve a suitable score for this variable. All scores for pedestrian facilities (observed variables) can be calculated by comparing existing conditions with the standards for each facility (see Appendixes A and B). Table 4 summarizes the scores, PLOS weights and PLOS percentage for the Main Street in Setia Tropika, based on Eqs. (1)–(4), and Appendixes A and B. The PLOS grade for this street is C according to the defined grades in this method, indicating that this street requires some improvements.

4. Discussion and conclusions

Suitable and enough infrastructures and facilities should be provided for pedestrian-friendly streets. Accordingly, a practical and suitable PLOS model is needed to evaluate pedestrian facilities and indicate improvements. Most previous PLOS methods have considered a limited range of pedestrian facilities. In addition, there are limited studies focusing on micro-level design factors, which have significant effects on the level of service. Moreover, the methodology of previous PLOS models is not easy to follow and cannot be connected to the

Table 3
The model estimates.

			Estimate	S.E.	C.R.	P
The main facilities	< —	Inclusive streets for walking	1.000			
The encouragement facilities	< —	Inclusive streets for walking	.510	.062	8.200	***
The convenience facilities	< —	Inclusive streets for walking	.760	.094	8.099	***
Curb ramp	< —	The main facilities	.890	.067	13.296	***
Bollard	< —	The main facilities	.686	.063	10.841	***
Driveway	< —	The main facilities	.803	.070	11.533	***
Surface material	< —	The main facilities	.881	.061	14.388	***
Tactile pavement	< —	The main facilities	.800	.065	12.376	***
Ramp	< —	The main facilities	1.000			
Width of the sidewalk	< —	The main facilities	.770	.057	13.403	***
Lighting	< —	The encouragement facilities	1.000			
Landscape and tree	< —	The encouragement facilities	.928	.079	11.746	***
Sitting area	< —	The encouragement facilities	.924	.083	11.107	***
Toilet	< —	The convenience facilities	.786	.065	12.108	***
Drinking Fountain	< —	The convenience facilities	1.000			
Elevator	< —	The convenience facilities	.726	.072	10.143	***
Trash receptacles	< —	The convenience facilities	.916	.074	12.379	***

*** The p value is less than 0.001.

Table 4
PLOS calculation results.

Factor (latent variable)	Wight	Facility (observed variable)	Wight	Score	Wight × score	PLOS$_{lvi}$	PLOS$_{lvi}$%	PLOS	PLOS%
The main facilities	1.00	Curb ramp	0.89	0.10	0.089	2.876	(2.876 / 5.83) × 100 = 49	(1 × 2.876) + (0.51 × 0.8066) + (0.76 × 1.4075) = 4.357066	((1 × 49) + (0.51 × 28) + (0.76 × 41)) / ((1 × 100) + (0.51 × 100) + (0.76 × 100)) × 42
		Bollard	0.69	0	0				
		Driveway	0.80	1	0.8				
		Sidewalk pavement	0.88	0.78	0.6864				
		Tactile Pavement	0.80	0	0				
		Ramp	1.00	0.70	0.7				
		Width of sidewalk	0.77	0.78	0.6006				
The encouragement facilities	0.51	Lighting	1.00	0	0	0.8066	(0.8066 / 2.85) × 100 = 28		
		Landscape and trees	0.93	0.62	0.5766				
		Seating area	0.92	0.25	0.23				
The convenience facilities	0.76	Toilet	0.79	0.25	0.1975	1.4075	(1.4075 / 3.44) × 100 = 41		
		Drinking fountains	1.00	0.25	0.25				
		Elevator	0.73	1	0.73				
		Trash receptacles	0.92	0.25	0.23				

design process. Therefore, this study proposes a new PLOS model to fulfil the needs of pedestrians by considering various facilities extracted from a wide range of developed guidelines, literature and interviews. The rating system used in the proposed PLOS model to evaluate pedestrian facilities at a micro level is easy to follow.

Various research emphasizes the lack of ability among existing studies to include the right combination of related factors for the facility evaluation process in PLOS studies. Maghelal and Capp (2011) focused on consideration of built environment attributes, which need to be combined with other effective factors for PLOS analysis. Singh and Jain (2011) argued that current PLOS methods are not inclusive for the entire walking environment. Kadali and Vedagiri (2016) emphasized the need to create a method that combines quantitative and qualitative factors to assess PLOS. The main contribution of the proposed PLOS model in this study is the right combination of all factors involved.

The model proposed in this study is applied to a collector street in the Setia Tropika area of Johor Bahru, Malaysia, and the same process can be applied to estimate the proposed PLOS for other street types or cities around the world. However, appropriate standard changes, and PAF, CFA and SOCFA recalculations for other cities and areas, should be considered. Therefore, the proposed PLOS can be utilized universally since the standards that are used in this model are extracted from universal standards. It can also be localized by applying PAF, CFA and SOCFA in the case study.

The limited number of advanced (and recent) PLOS models indicate the problems with pedestrian-friendly streets and suggest improvements in order to raise PLOS grades (e.g., Asadi-Shekari et al., 2013a, 2014). However, these models do not consider users' perceptions and just focus on guidelines and literature. The proposed PLOS model in this study can be used to improve existing conditions, while considering pedestrians' perceptions. These improvements can be determined by comparing existing conditions with standards. For instance, the score for landscape and trees (see Table 3 and Appendix B) can be increased from 0.62 ($D = 15$, $C = ((1790 \times 2) - 179) \times 9/15 = 2040.6$, $N = (1790 \times 2) - 179 = 3401$, $P_1 = 2040.6/3401 = 0.60$, $F = 2040.6 - 0 = 2040.6$, $P_2 = 2040.6/3401 = 0.60$, $NI = 2$, $I = 3$, $P_3 = 2/3 = 0.67$; so, $S = (0.60 + 0.60 + 0.67)/3 = 0.62$) to 1 if distances between trees are decreased from 15 m to 9 m and trees located at the stipulated standard distance (at two intersections) are removed. Scores for rubbish bins (see Table 3 and Appendix B) can also be increased from 0.25 ($C = 500 + 400 = 900$ m, $N = 1790 \times 2 = 3580$ m, $S = 900/3580 = 0.25$) to 1 if rubbish bins are provided along 2680 m of the street. All improvements can be found by the same process. These improvements can be prioritized, based on the weights of the facilities estimated by SOCFA (see Table 3).

Results show that the 'main facilities' have the highest association with inclusive pedestrian-friendly streets, followed by 'convenience facilities' and 'encouragement facilities' (see Fig. 2). Among the main facilities, a ramp has the highest association, followed by a curb ramp, sidewalk pavement, tactile pavement, driveway, width of sidewalk and bollard (see Fig. 2). Among convenience facilities, drinking fountains have the highest association, followed by rubbish bins, toilets and a lift (see Fig. 2). Among encouragement facilities, lighting has the highest association, followed by the landscape, trees and seating areas (see Fig. 2).

The proposed PLOS can also be used to identify the type of pedestrian facilities that need further improvements. The PLOS score for the main facilities in Setia Tropika is 2.876. The maximum PLOS available for the main facilities is 5.83 (see Table 3). Therefore, the PLOS percentage for the main facilities on this street is 49 (see Table 3) and the associated PLOS grade is C. This grade is the same for convenience facilities, but the PLOS percentage for encouragement facilities is 28, which is associated with PLOS grade D. This shows that important encouragement facilities, such as lighting and seating areas, are inadequate on this street, while the main facilities and convenience facilities also need some improvement.

Although this study just focuses on pedestrians, the street conditions for other non-motorized street users, such as cyclists, could be evaluated in further studies using a similar process. The model presented here could be modified for use with other human settlements, such as rural areas and suburban areas, by considering the standard changes for street types, and PAF, CFA and SOCFA recalculation for the weights. Future studies could develop the PLOS model in the form of software promoting an easier calculation process. The model could also be used by urban designers for the design of new inclusive, pedestrian-friendly streets, in addition to improving existing streets.

Acknowledgments

Appendix A. Standards of pedestrian facilities for collector streets

Sources: Asadi-Shekari et al. (2013a, 2014 and 2015b), Clarke (2008); City of Calgary (2008); Sutherland and Morrish (2006); City of Whittlesea (2009); NARRABRR SHIRE COUNCIL (2001); City of Charles Sturt (2009); Heramb (2007); Vanderslice (1998); Ashland City Council (1999); Access Minneapolis (2008); CDOT (2007); Pima County (2005); Neighborhood Streets Project Stakeholders (2000); City of Aurora (2007); Burden (1999); Boodlal (2001); UTTIPEC (2009); NewYork City Department of Transportation (2009); RDM (2010) and City of Tacoma (2009)

Facility	Standards for collector streets
Curb ramp	1. Curb ramps shall be located or protected to prevent their obstruction by parked vehicles 2. Minimum top landing is 1.2 × 1.2 m and the maximum slope is 2% 3. Minimum ramp width is 1.2 m and ramp slope is from 5% – 8.3% 4. Maximum flared side cross slope is 10%
Bollard	1. Removable and lockable bollards should be provided across both entrances spaced not more than 1.5 m apart to control vehicle access and also min 1.2 m apart to cross wheelchair user 2. Height of bollard varies but it is around 0.75–1.2 m 3. Allow 0.45 m clear space from the front of the curb 4. They should be high visible
Driveway	1. It should not be wider than garage 2. It should be 9 m far from major street intersection, 6 m from other intersections 3. Min width is 3.6 m and max width is 7.5 m 4. Driveways must be located at least 3 m from the outside of the trunk of any existing street trees Max slope is 2% in sidewalk, 10% in flare and 8.3–10% in ramp
Sidewalk pavement	1. It should be stable, anti-slip, smooth and continuous 2. Surface discontinuities may not exceed 1.25 cm and vertical discontinuities should be between 0.6 cm and 1.25 cm
Tactile Pavement	Guiding 1. A distance of 0.60 – 0.80 m from any obstruction should be provided 2. Minimum width is 0.30 m and height is approximately 0.005 m for the raised portion 3. Should be preferably canary yellow Warning 1. Should be placed at the bottom of curb ramps and other warning locations such as raised crosswalks, intersections, the edge of transit platforms and when the walking direction changes 2. Should be installed across the full width of ramps, 0.60 m up the ramp and set back 0.15 – 0.20 m from the bottom of the curb
Ramp	1. Max slope is 8.3% 2. Min width is 1.2 m 3. Suitable handrail should be provided
Width of sidewalk	1. Min footpath width is 1.8 m but 2.4 m is recommended 2. Frontage zone has min 0.15 m width
Lighting	1. Enough light should be provided 2. Pedestrian scale is important 3. The light pole should be centered a min of 0.9 m off the face of curb and from any accessible structure such as shelter 4. It should be full cut off fixtures which focus light downwards 5. The light poles should be max 9 m apart to have enough light
Landscape and trees	1. Tree branches should have a vertical clearance of at least 2.4 m 2. Trees should be at least 7.6 m far from intersection 3. Trees should be no more than 9 m apart to provide continuous tree canopy 4. Trees should be planted on both sides of street
Seating area	1. They should be considered in planting and frontage zone 2. They should be located a min of 0.6 m setback from the face of the curb 3. Min 9 m from an intersection should be provided 4. They should be provided in all bus stops 5. They should be provided every 200 – 400 m 6. A space of 1.2 m should be provided at the end of seats to enable strollers and wheelchairs to be parked 7. All seating areas should be set back at least 0.6 m from pedestrian traffic routes 8. A space of 1.5 m should be provided between the front edge of the seat and any stationary obstacles such as a water fountain, trash receptacle or sign post
Toilet	1. Public toilets should be located near every bus-stops and definitely located at each Rapid Transit Station and adjacent to parks property or playgrounds 2. Frequency of location of toilets should be every ˜500 – 800m 3. Minimum of 1.7 × 1.8 m should be considered for wheelchair users
Drinking fountains	1. They should be located within furnishings zone near playgrounds or outdoor eating areas and adjacent to shelters and paved areas along walkways and plazas 2. They should be provided every 400 m 3. At least 0.6 m from the pedestrian traffic routes should be provided 4. Maximum height is 0.91 m for wheelchair accessible drinking fountains

Elevator	1. Each sky bridge should have lifts, and all lifts should have Braille buttons and audio announcement systems
	2. Elevator/lift should be provide on both the entrances and exits of the sky bridges and should have minimum internal dimensions of 1.4×1.4 m
	3. Height of the call button is between 0.9 and 1 m
	4. Inside lift should have a handrail
Trash receptacles	1. It should be centred in furnishing zone when zone is 0.9 m wide or greater
	2. It should be 9 m far from intersection
	3. Min 0.6 m from the face of curb should be provided
	4. One receptacle should be located at each playground, and adjacent to benches
	5. It should have min1.2 m clearance from bus stop infrastructure
	6. It should be provided every 200 – 400 m like bench

Appendix B. S calculation

Sources: Asadi-Shekari et al. (2013a, 2014 and 2015b).

Facility	Score
Curb ramp	C = Number of standard curb ramps
	N = Total number of curb ramps the street needs
	P = C/N
	$S = \begin{cases} 1 \ if \ P \geq 1 \\ P \ if \ P < 1 \\ 0 \ if \ street \ does \ not \ need \ a \ curb \ ramp \end{cases}$
Bollard	C = Number of standard bollards rows
	N = (total crosswalks + total median crosswalk sections that street needs) $\times 2$
	P = C/N
	$S = \begin{cases} 1 \ if \ P \geq 1 \\ P \ if \ P < 1 \end{cases}$
Driveway	C = Number of standard driveways
	N = Total driveways that street has
	S = C/N
	S = 1 if there is no driveway
Sidewalk pave-ment	W = Width of footpath (m)
	C = Area of standard pavement (m^2)
	$N = \begin{cases} (\text{length of street (both sides)} - \text{length of intersections}) \times 1.8 \ if \ W < 1.80 \ m \\ (\text{length of street(both sides)} - \text{length of intersections}) \times W \ if \ W \geq 1.80 \ m \end{cases}$
	S = C/N
	If W varies in different parts of street
	W_i = Width of footpath in section i
	i = 1, 2, 3, …, k (different parts of street with various width of the footpath)
	C_i = Area of standard pavement in section i (m^2)
	$N_i = \begin{cases} (\text{length of street (in section } i)) \times 1.8 \ if \ W_i < 1.80 \ m \\ (\text{length of street in section } i) \times W_i \ if \ W_i \geq 1.80 \ m \end{cases}$
	PC_i = C_i/N_i
	L_i = Length of street in section i (m)
	$S = (\sum_{i=1}^{k} (PC_i \times L_i))/(\text{length of street (both sides)} - \text{length of intersections})$
Tactile Pavement	C = Length of the standard tactile pavement (m)
	N = Length of tactile pavement the street requires (m)
	P = C/N
	$S = \begin{cases} 1 \ if \ P \geq 1 \\ P \ if \ P < 1 \end{cases}$
Ramp	C = Number of standard ramps
	N = Number of ramps that street needs
	P = C/N
	$S = \begin{cases} 1 \ if \ P \geq 1 \\ P \ if \ P < 1 \\ 1 \ if \ street \ does \ not \ need \ ramp \end{cases}$
Width of sidewalk	W = Width of footpath (m)
	C = Area of standard footpath (m^2)
	$N = \begin{cases} (\text{length of street (both sides)} - \text{length of intersections}) \times 1.8 \ if \ W < 1.80 \ m \\ (\text{length of street(both sides)} - \text{length of intersections}) \times W \ if \ W \geq 1.80 \ m \end{cases}$
	S = C/N
	If W varies in different parts of street
	W_i = Width of footpath in section i
	i = 1, 2, 3, …, k (different parts of street with various width of the footpath)
	C_i = Area of standard footpath in section i (m^2)
	$N_i = \begin{cases} (\text{length of street (in section } i)) \times 1.8 \ if \ W_i < 1.80 \ m \\ (\text{length of streetin in section } i) \times W_i \ if \ W_i \geq 1.80 \ m \end{cases}$
	PC_i = C_i/N_i
	L_i = Length of street in section i (m)
	$S = (\sum_{i=1}^{k} (PC_i \times L_i))/(\text{length of street (both sides)} - \text{length of intersections})$

Lighting	$C = \begin{cases} ((\text{Length of street with pedestrian lighting} - \text{total length of intersections}) \times 9)/D \text{ if } D > 9\,m \\ \text{Length of street with pedestrian lighting} - \text{total length of intersections if } D \le 9m \end{cases}$

D = Distance between light poles (m)

N = (length of street (both sides) -intersections length) (m)

$P = C/N$

$S = \begin{cases} 1 \text{ if } P \ge 1 \\ P \text{ if } P < 1 \end{cases}$

If D varies in different parts of street

$S = \sum_{i=1}^{k} C_i / \sum_{i=1}^{k} N_i$

i = 1, 2, 3,...k (different parts of street with various distances between light poles)

$C_i = \begin{cases} ((\text{Length of street with pedestrian lighting in section } i) \times 9)/D \text{ if } D > 9\,m \\ \text{Length of street with pedestrian lighting in section } i \text{ if } D \le 9\,m \end{cases}$

N_i = length of street in section i (m)

Landscape and tre-es	D = Distance between trees (m)

$C = \begin{cases} \dfrac{((\text{Length of street with tree} - \text{total length of intersections and their considered standard limitations}) \times 9)}{D} \text{ if } D > 9 \\ \text{Length of street with tree} - \text{total length of intersections and their considered standard limitations if } D \le 9 \end{cases}$

N = Length of street (both sides)-total length of intersections and their considered standard limitations (m)

$P_1 = C/N$

If D varies in different parts of street

$C_i = \begin{cases} ((\text{Length of street with tree in section } i - \text{considered standard limitations}) \times 9)/D \text{ if } D > 9 \\ \text{Length of street with tree in section } i - \text{considered standard limitations if } D \le 9 \end{cases}$ i = 1, 2, 3,…, k (different parts of street with various distances between trees)

N_i = Length of street (in section i) – considered standard limitations (m)

$P_1 = \sum_{i=1}^{k} C_i / \sum_{i=1}^{k} N_i$

$F = C$ – length of street that does not have vertical clearance

N = Length of street (both sides)-total length of intersections and their considered standard limitations (m)

$P_2 = F/N$

If D varies in different parts of street

$F_i = C_i$ – length of street that does not have vertical clearance in section i

N_i = Length of street (section i)- considered standard limitations (m)

$P_2 = \sum_{i=1}^{k} F_i / \sum_{i=1}^{k} N_i$ i = 1, 2, 3,…, k

NI = Number of intersections with considered standard limitations for trees

I = Number of total intersections

$P_3 = NI/I$

$S = (P_1 + P_2 + P_3)/3$

Seating area	C = Length of street with standards seating area + their support length (m)

N = Length of street (in both sides) (m)

$S = C/N$

Toilet	C = Length of street with standards toilets + their support length (m)

N = Length of street (m)

$S = C/N$

Drinking fountains	C = Length of street with standards drinking fountains + their support length (m)

N = Length of street (m)

$S = C/N$

Elevator	C = Number of standard lifts

N = Number of lifts that street needs

$S = C/N$

S = 0 If street does not have lift

Trash receptacles	C = Length of street with standards trash receptacle area + their support length (m)

N = Length of street (both sides) (m)

$S = C/N$

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